Title: Beyond the Standard Model (Review) - Lecture 11

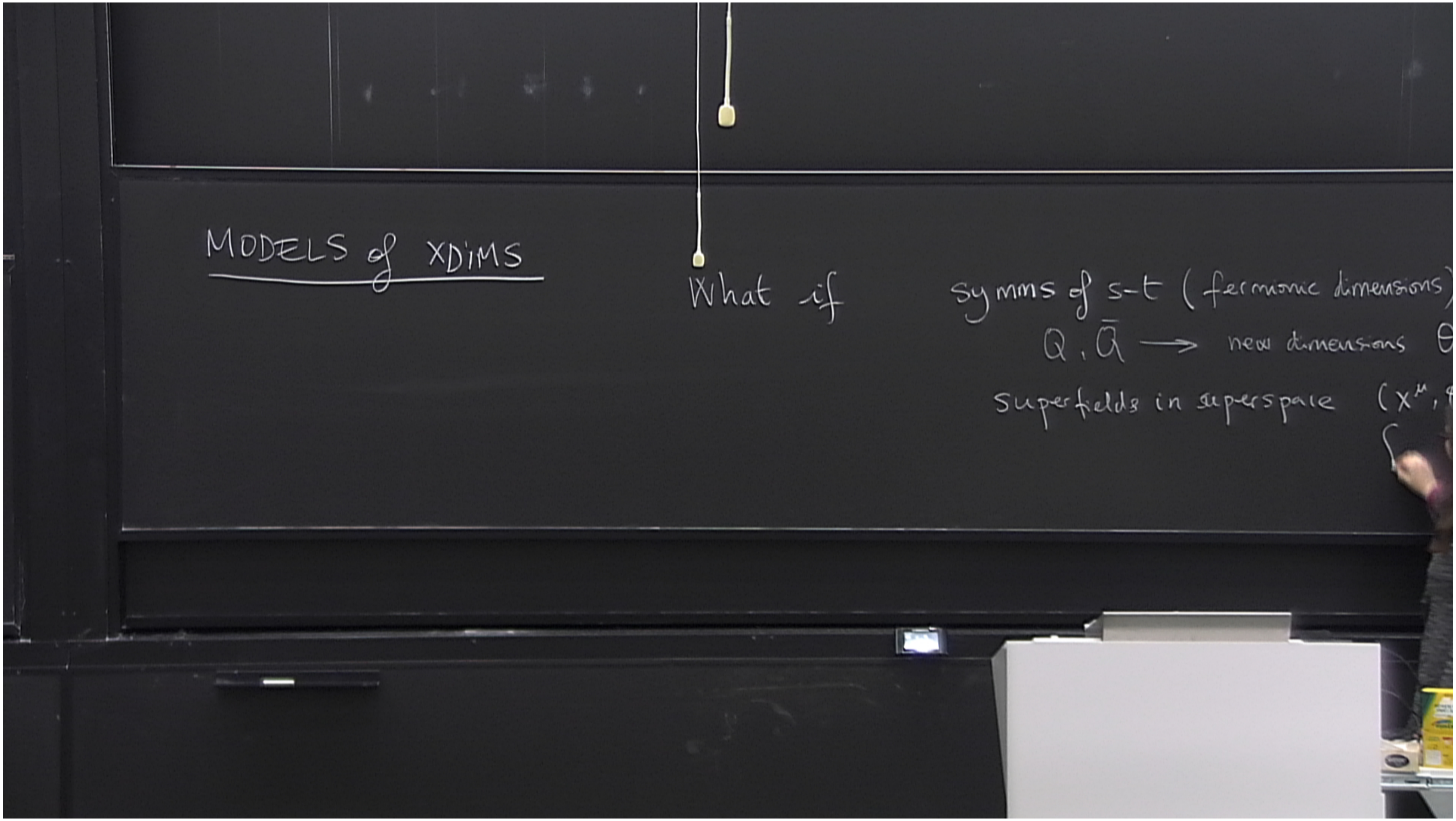
Date: Feb 28, 2012 09:00 AM

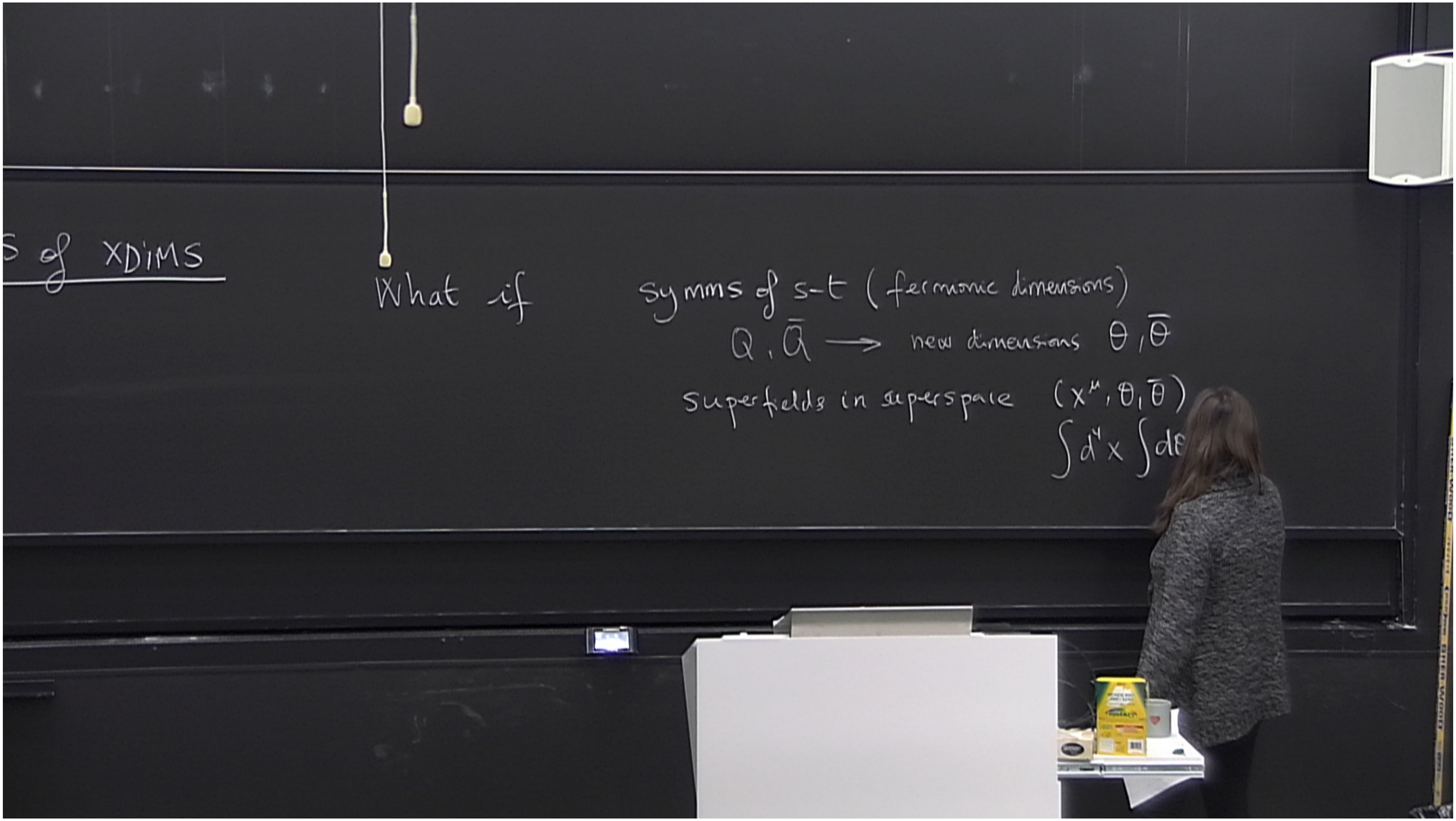
URL: http://www.pirsa.org/12020092

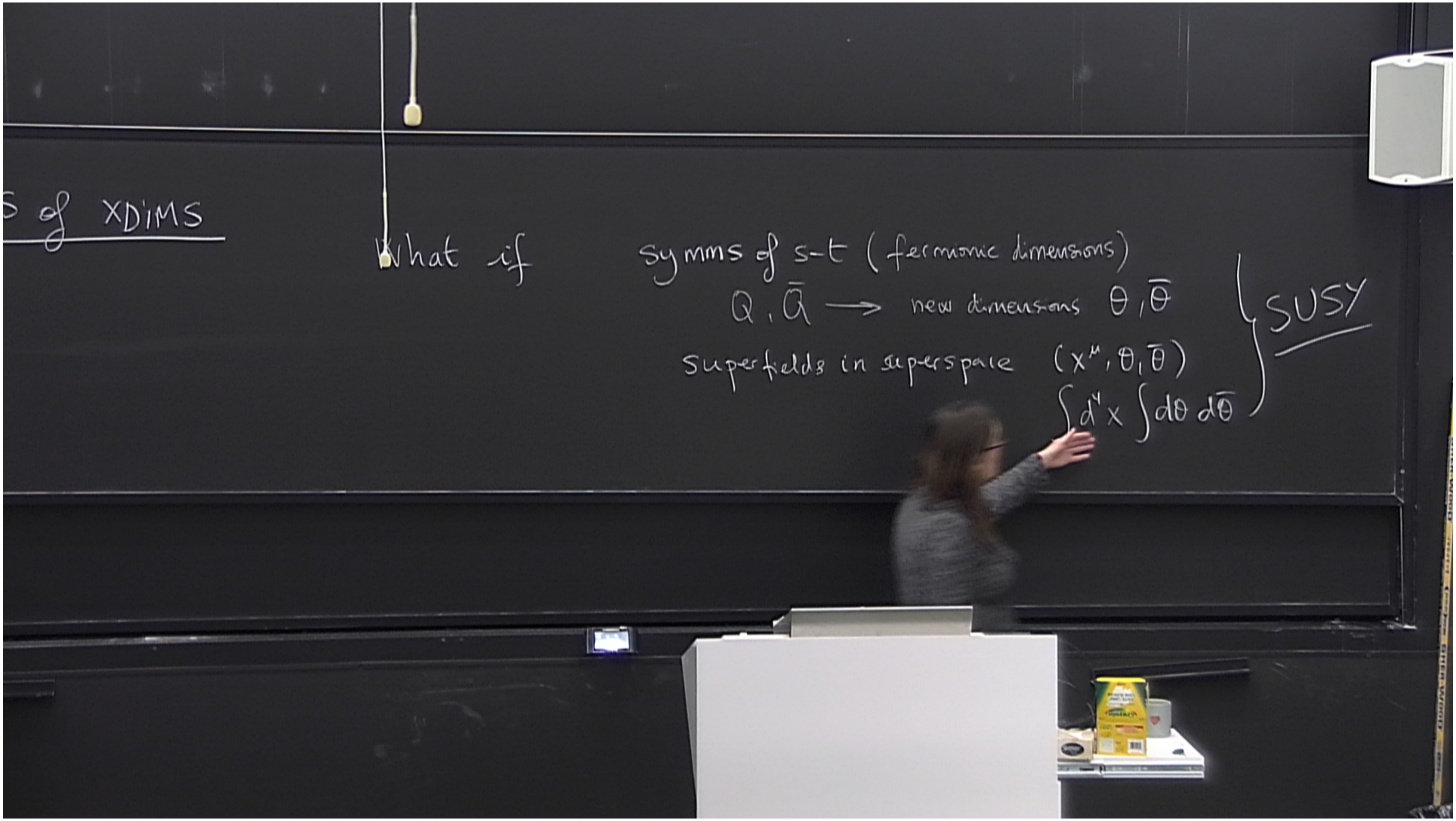
Abstract:

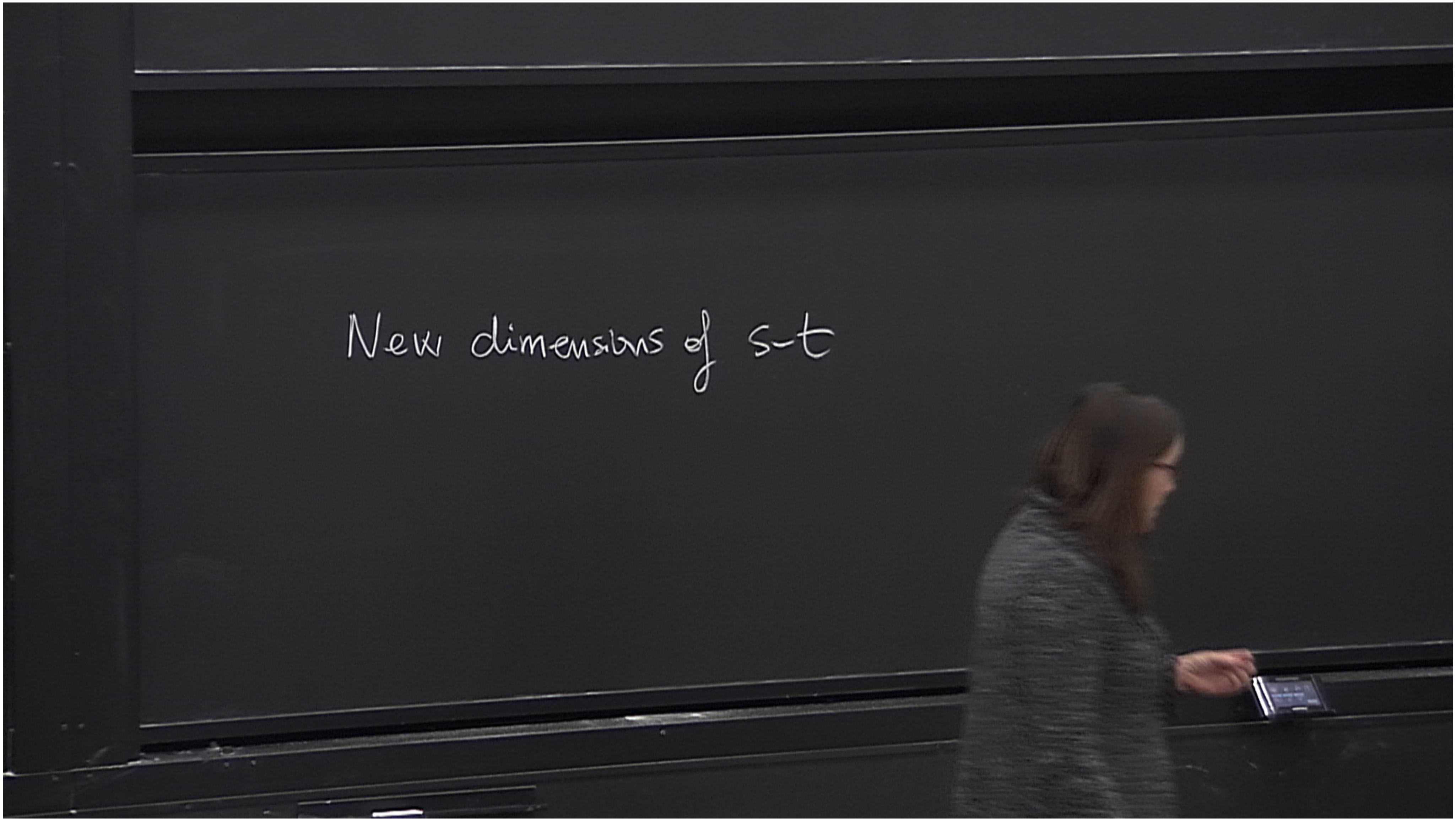
MODELS of XDIMS

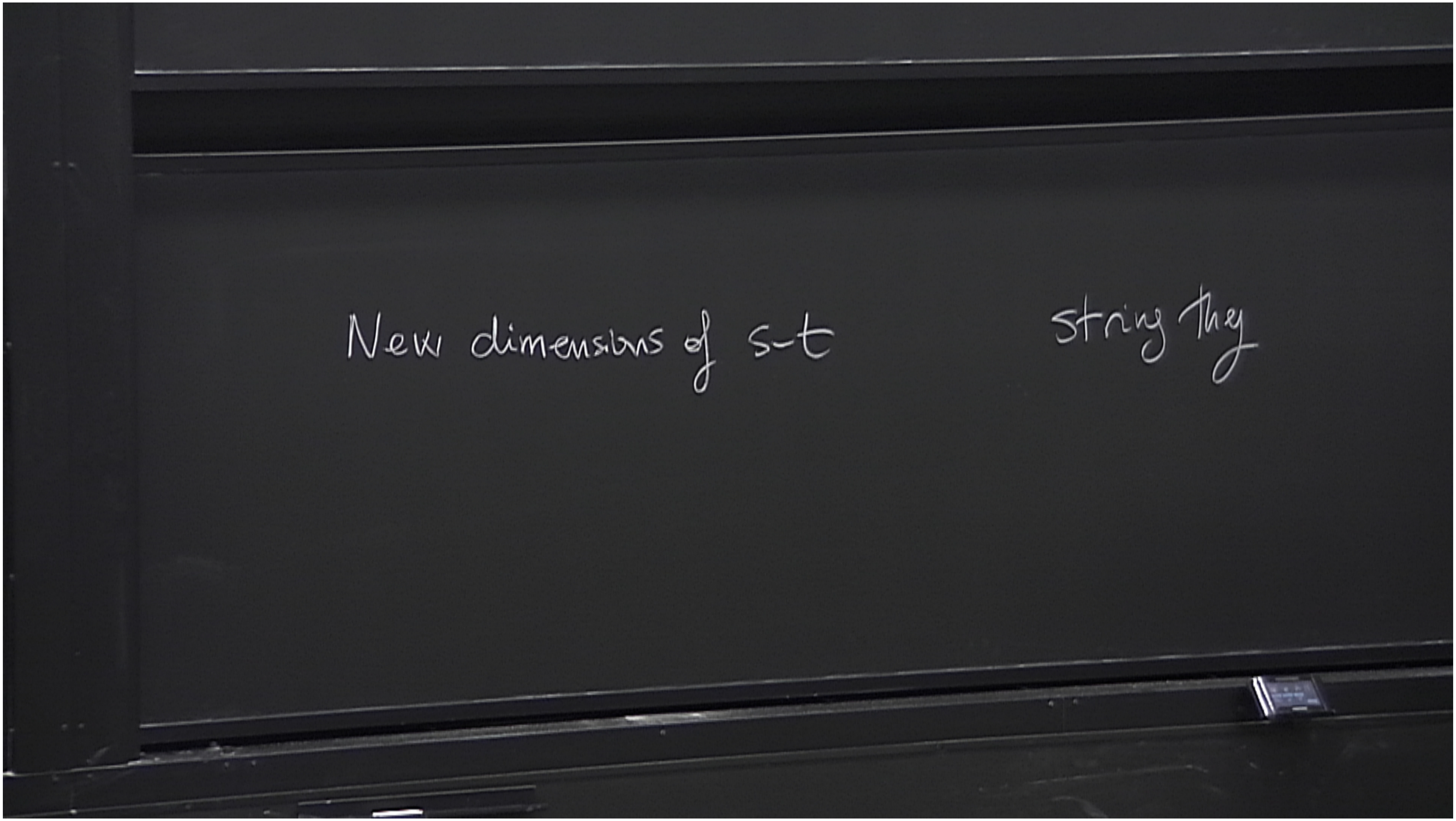
What if sy

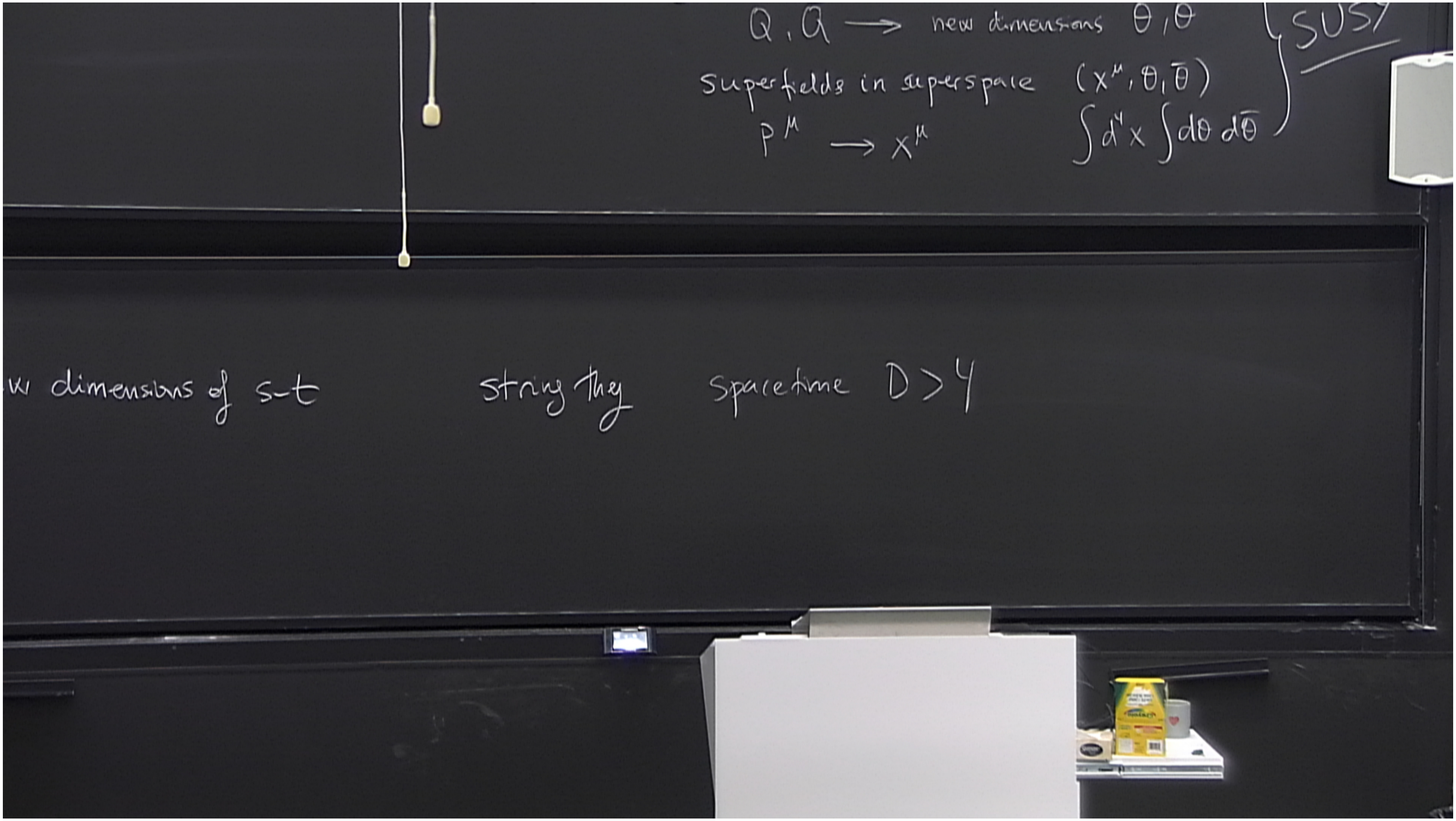

MODELS of XDIMS
What if
symms of s-t (fermionic dimensions)
$Q, \bar{Q} \longrightarrow$ new dimensions θ
superfields in superspace $(x^\mu,$

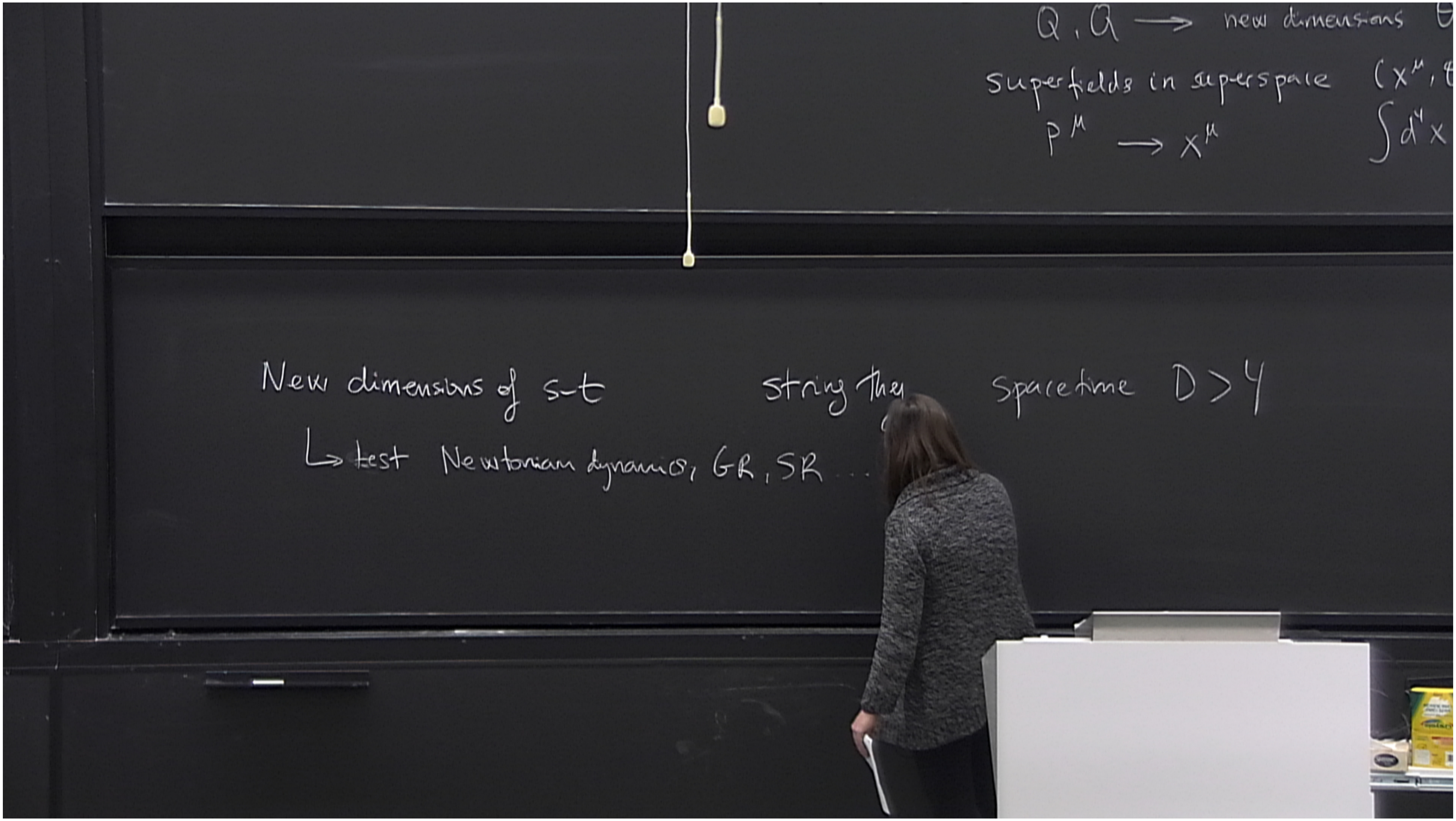

s of XDIMS
What if
symms of s-t (fermionic dimensions)
$Q, \bar{Q} \longrightarrow$ new dimensions $\theta, \bar{\theta}$
superfields in superspace $(x^\mu, \theta, \bar{\theta})$
$\int d^4x \int d\theta$


s of XDIMS
What if
symms of s-t (fermionic dimensions)
$Q, \bar{Q} \longrightarrow$ new dimensions $\theta, \bar{\theta}$
superfields in superspace $(x^\mu, \theta, \bar{\theta})$
$\int d^4x \int d\theta\, d\bar{\theta}$
SUSY

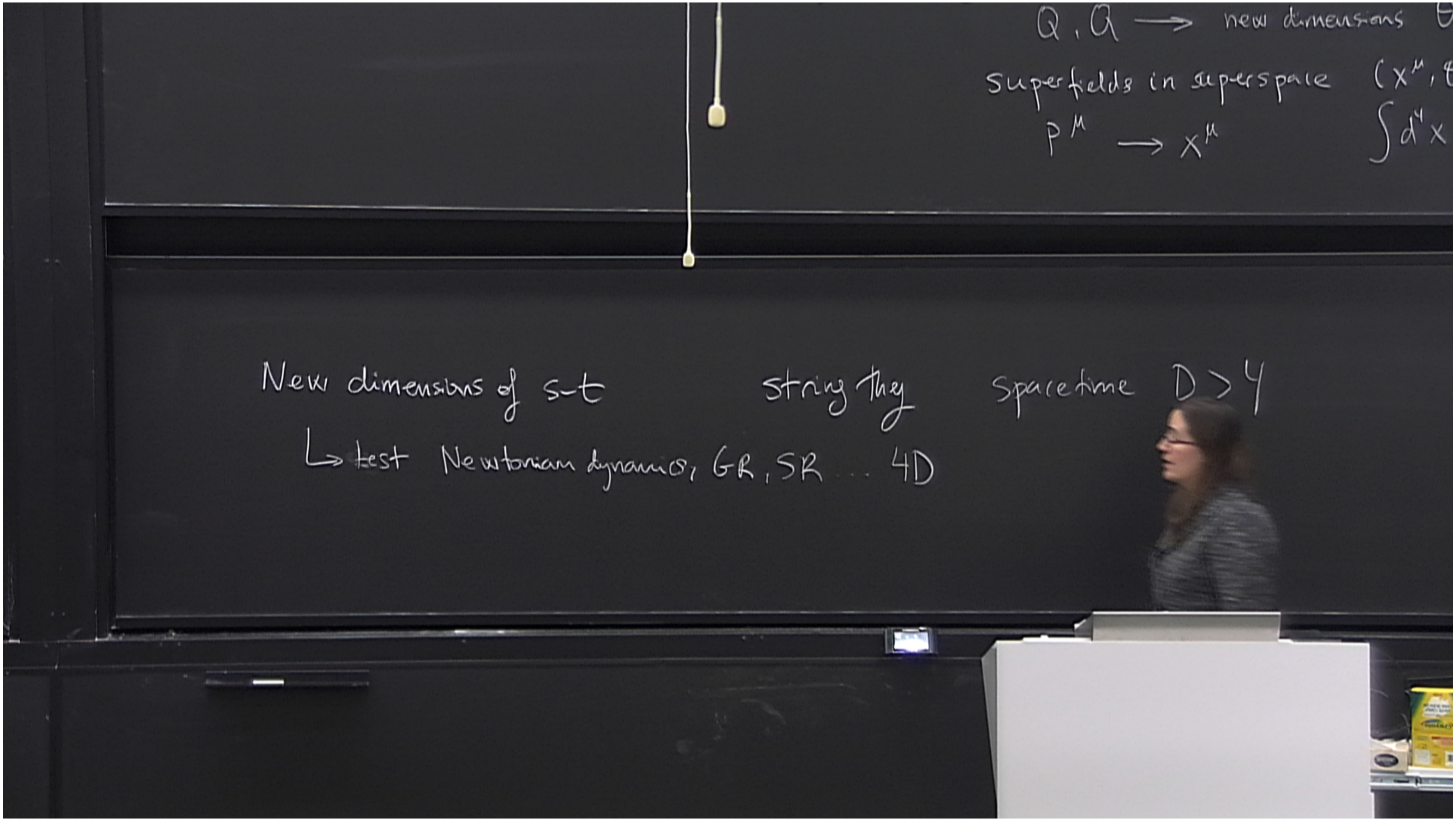

New dimensions of s-t

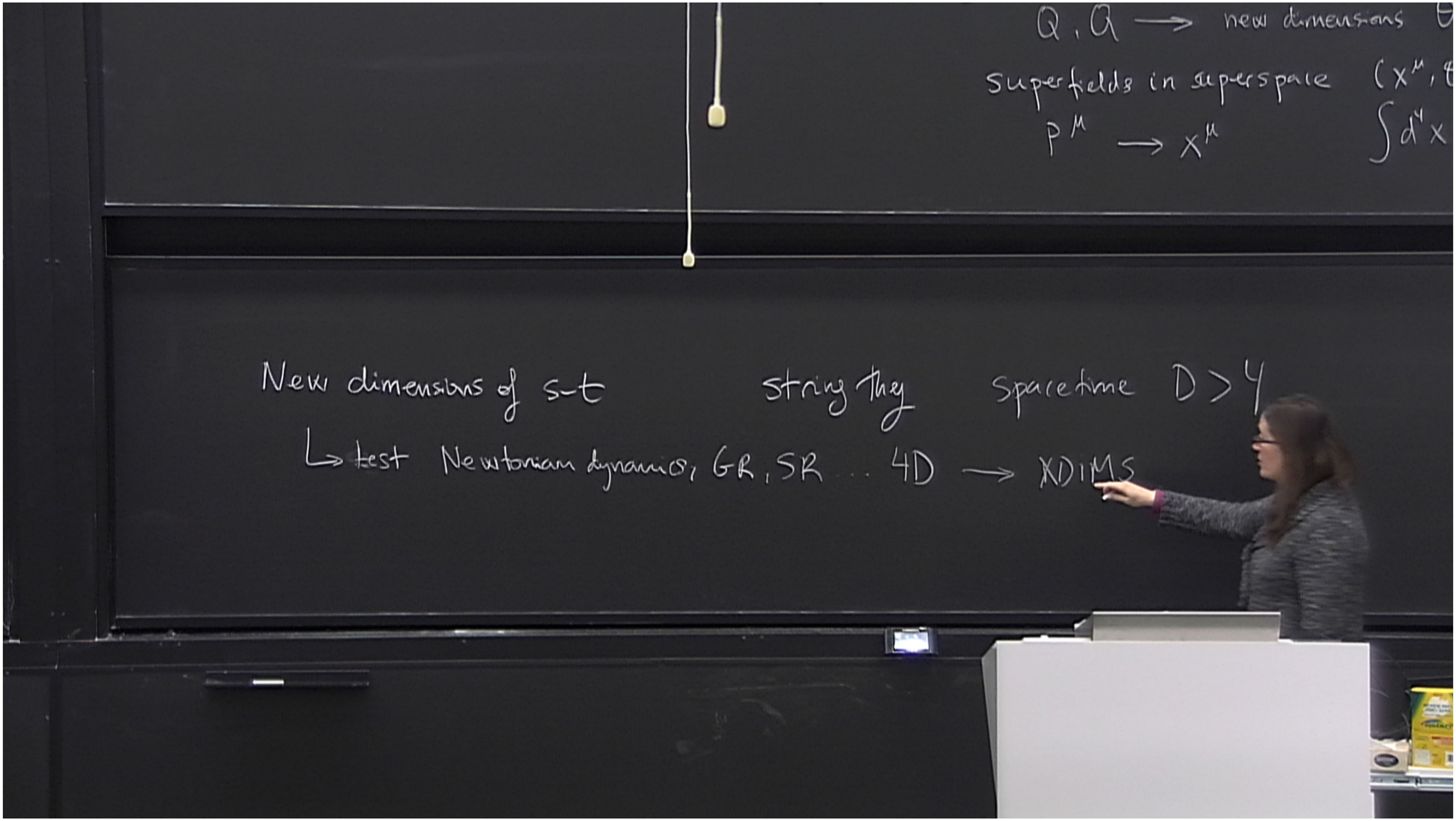

New dimensions of s-t
string thy

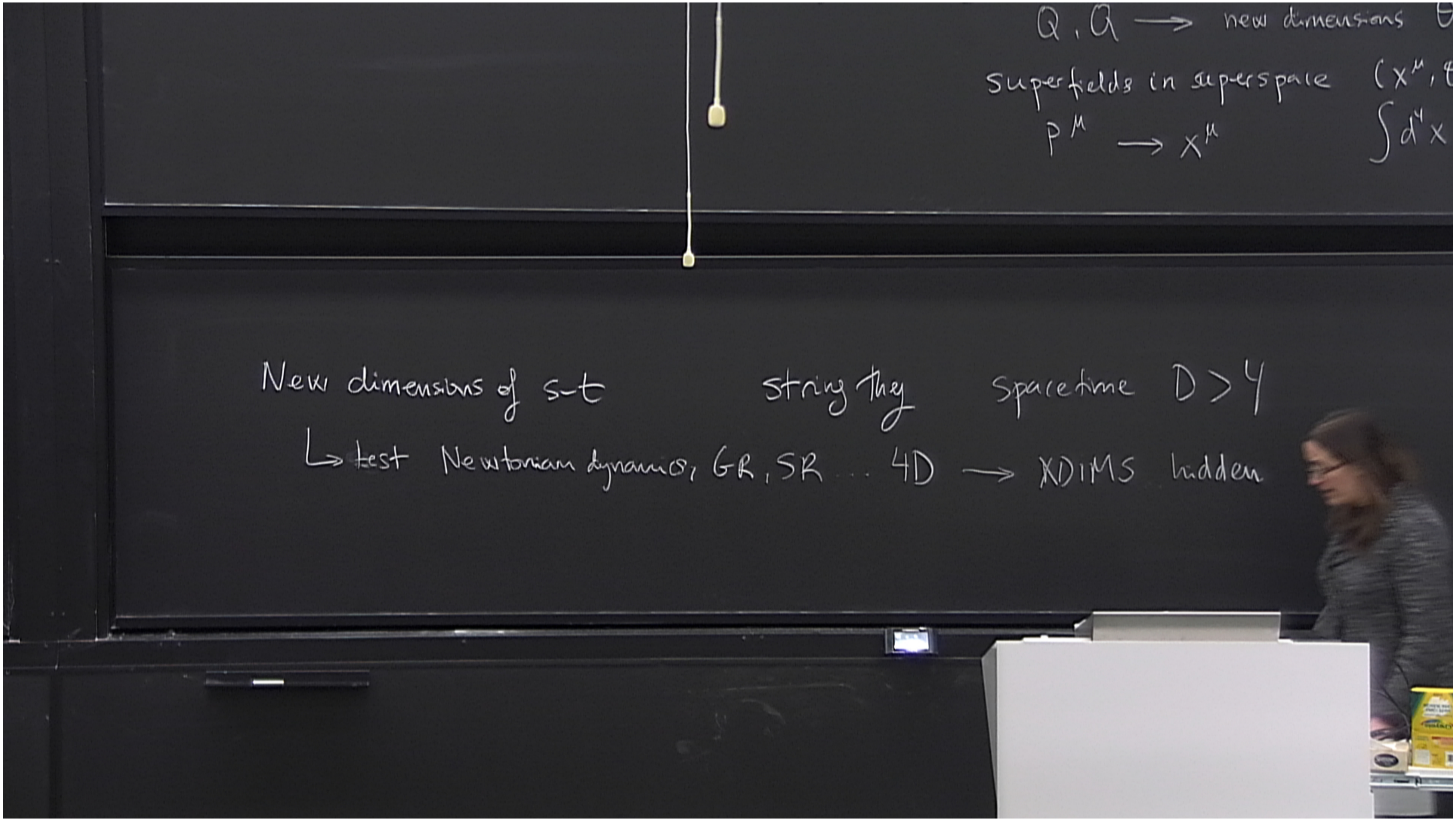

Q, Q̄ → new dimensions θ, θ̄
SUSY
superfields in superspace (x^μ, θ, θ̄)
p^μ → x^μ
∫d^4x ∫dθ dθ̄
w dimensions of s-t
string thy
spacetime D > 4



Q, Q → new dimensions θ
superfields in superspace (x^μ, θ
p^μ → x^μ
∫d^4x
New dimensions of s-t
string they
spacetime D > 4
↳ test Newtonian dynamics, GR, SR ...


Q, Q → new dimensions θ
superfields in superspace (x^μ, θ
p^μ → x^μ
∫d^4x
New dimensions of s-t
string thy
spacetime D > 4
↳ test Newtonian dynamics, GR, SR ... 4D


Q, Q → new dimensions
superfields in superspace (x^μ,
$p^\mu \to x^\mu$
$\int d^4x$
New dimensions of s-t
string thy
spacetime D > 4
↳ test Newtonian dynamics, GR, SR ... 4D → XDIMS



$Q, \bar{Q} \longrightarrow$ new dimensions θ
superfields in superspace $(x^\mu, \theta$
$p^\mu \longrightarrow x^\mu$ $\int d^4x$
New dimensions of s-t
string thy
spacetime $D > 4$
↳ test Newtonian dynamics, GR, SR ... 4D $\longrightarrow$ XDIMS hidden

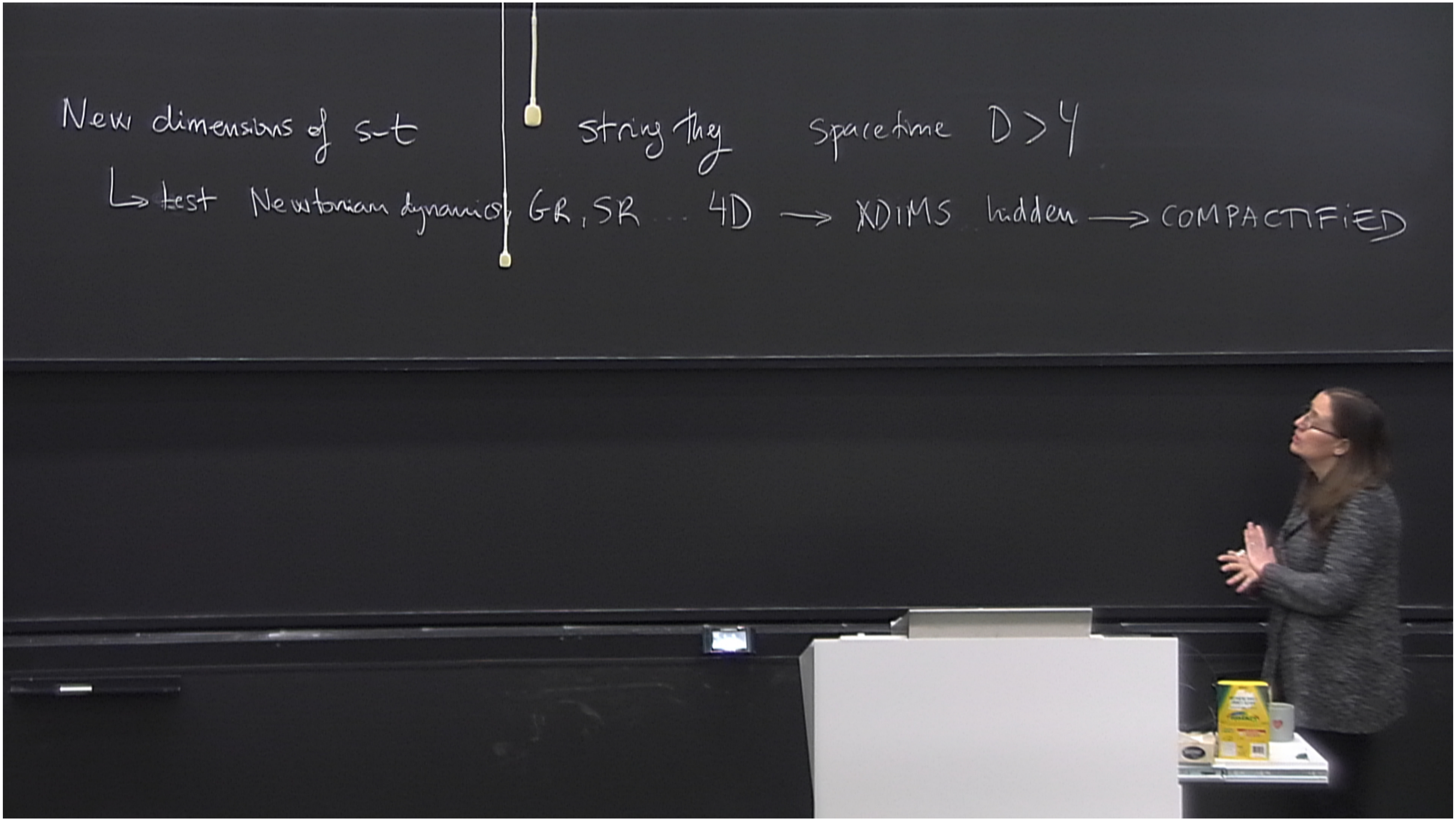
$Q, \bar{Q} \longrightarrow$ new dimensions $\theta, \bar{\theta}$ SU

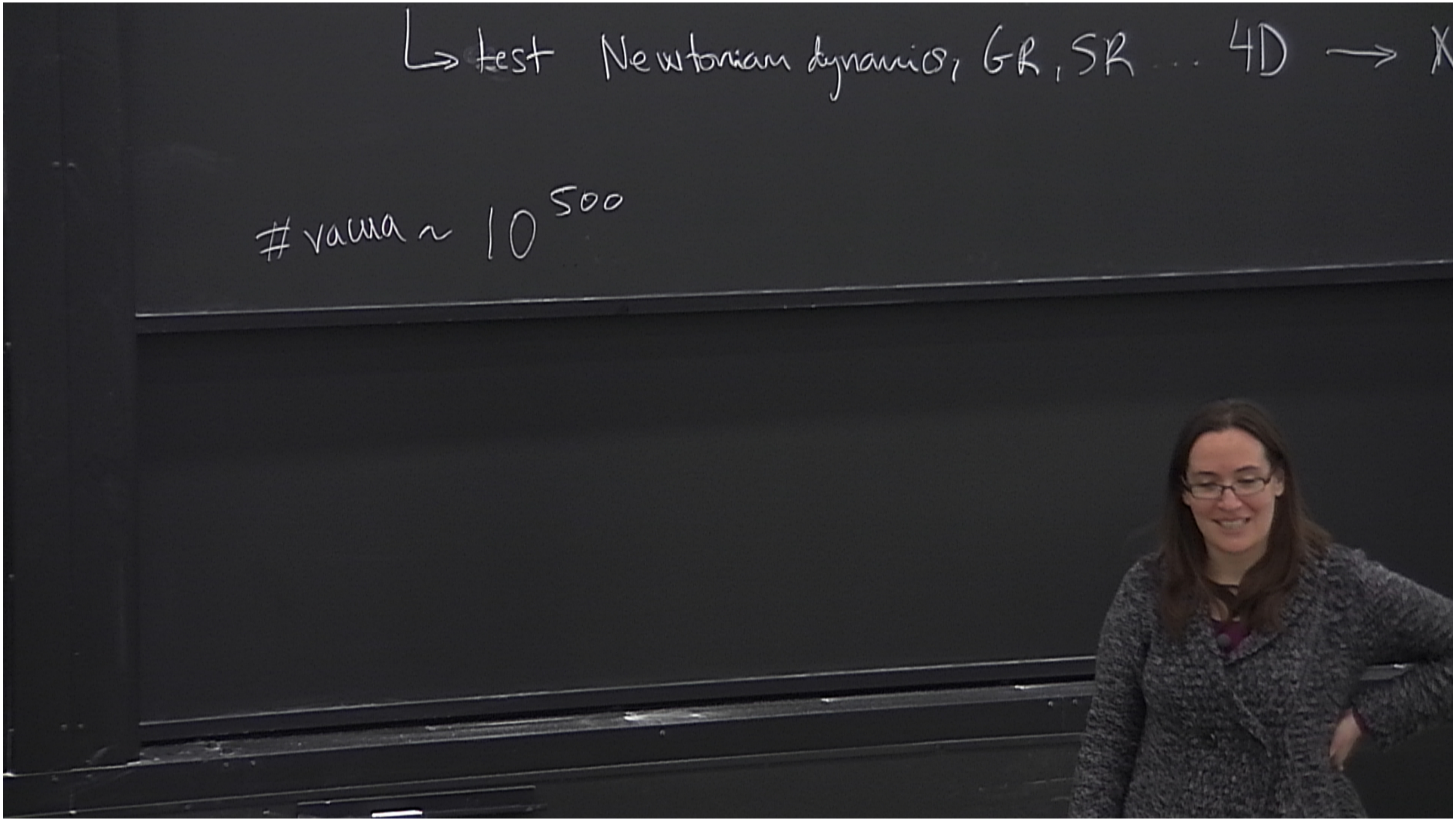
superfields in superspace $(x^\mu, \theta, \bar{\theta})$

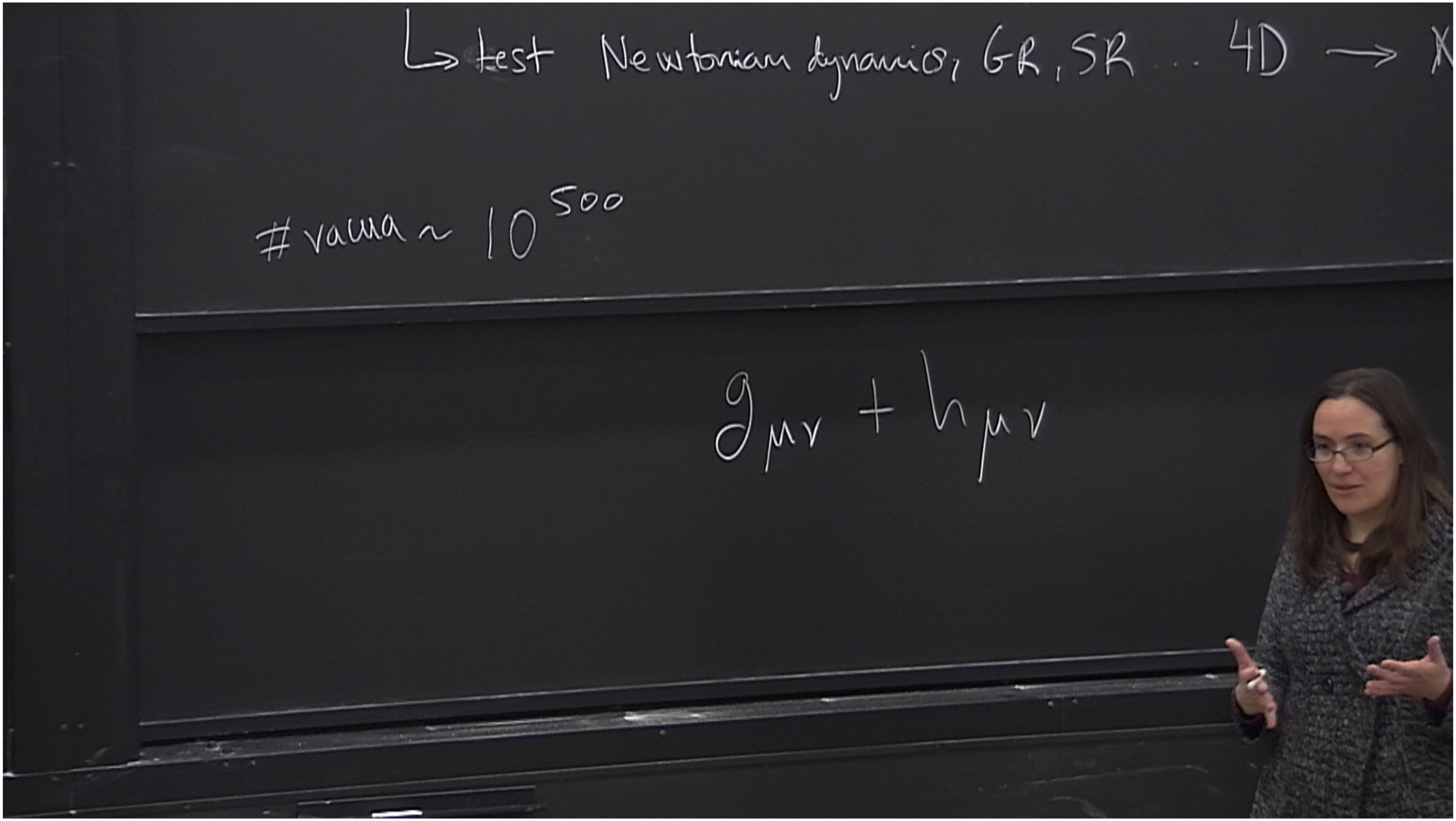
$p^\mu \longrightarrow x^\mu$ $\int d^4x \int d\theta \, d\bar{\theta}$

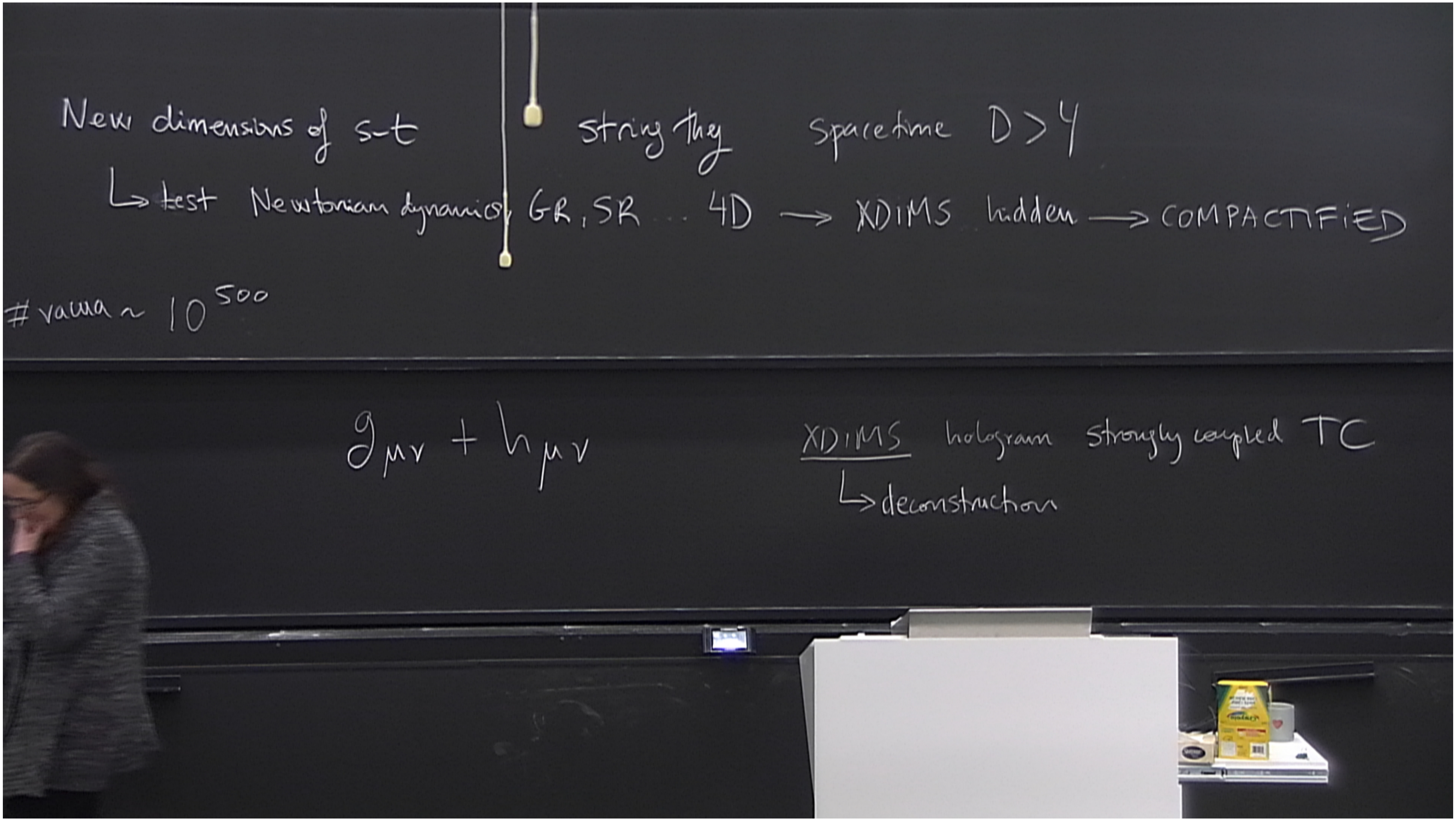
New dimensions of s-t string thy spacetime $D > 4$

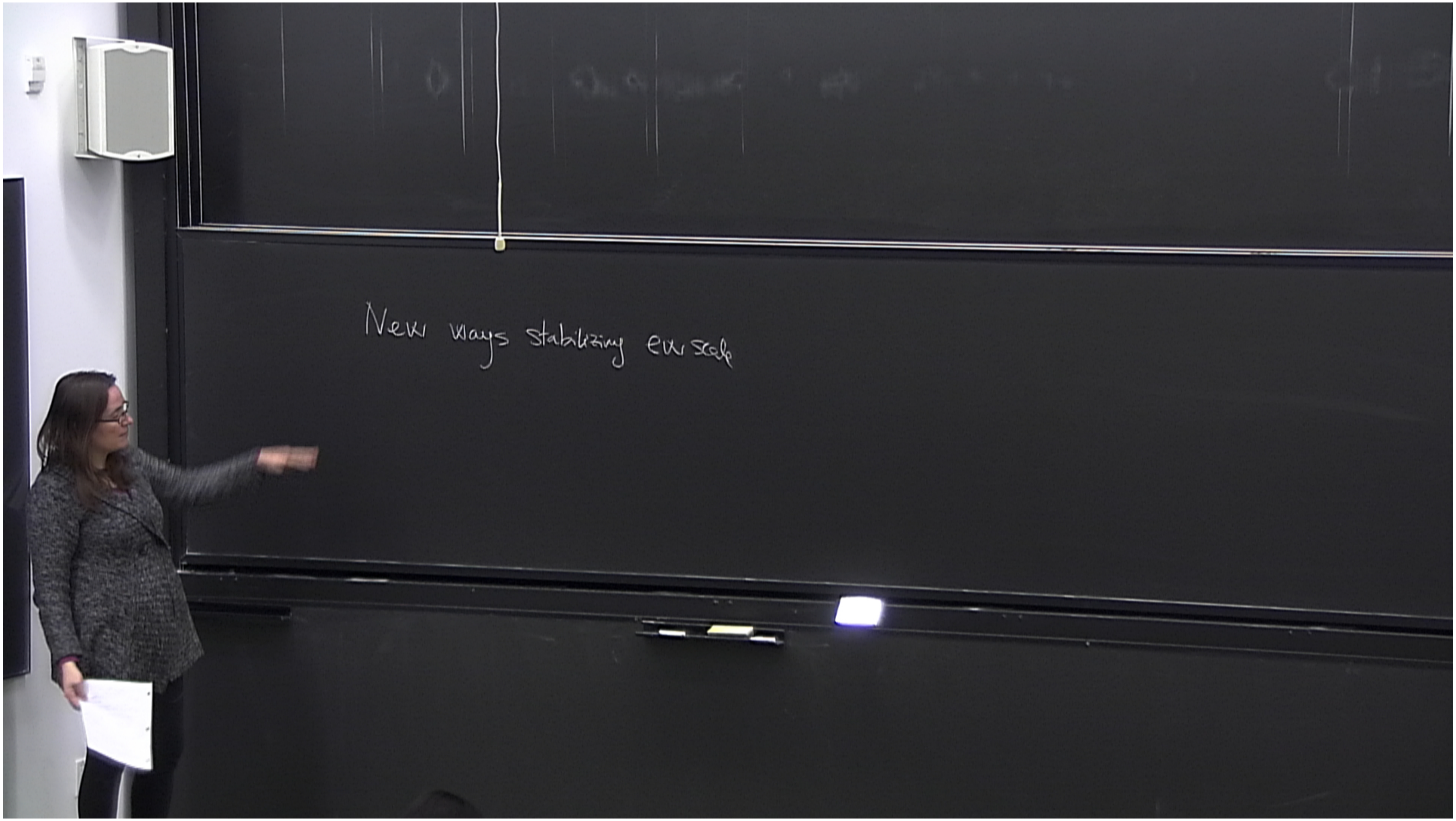
↳ test Newtonian dynamics, GR, SR ... 4D $\longrightarrow$ XDIMS hidden $\longrightarrow$ COMPACTIFIED

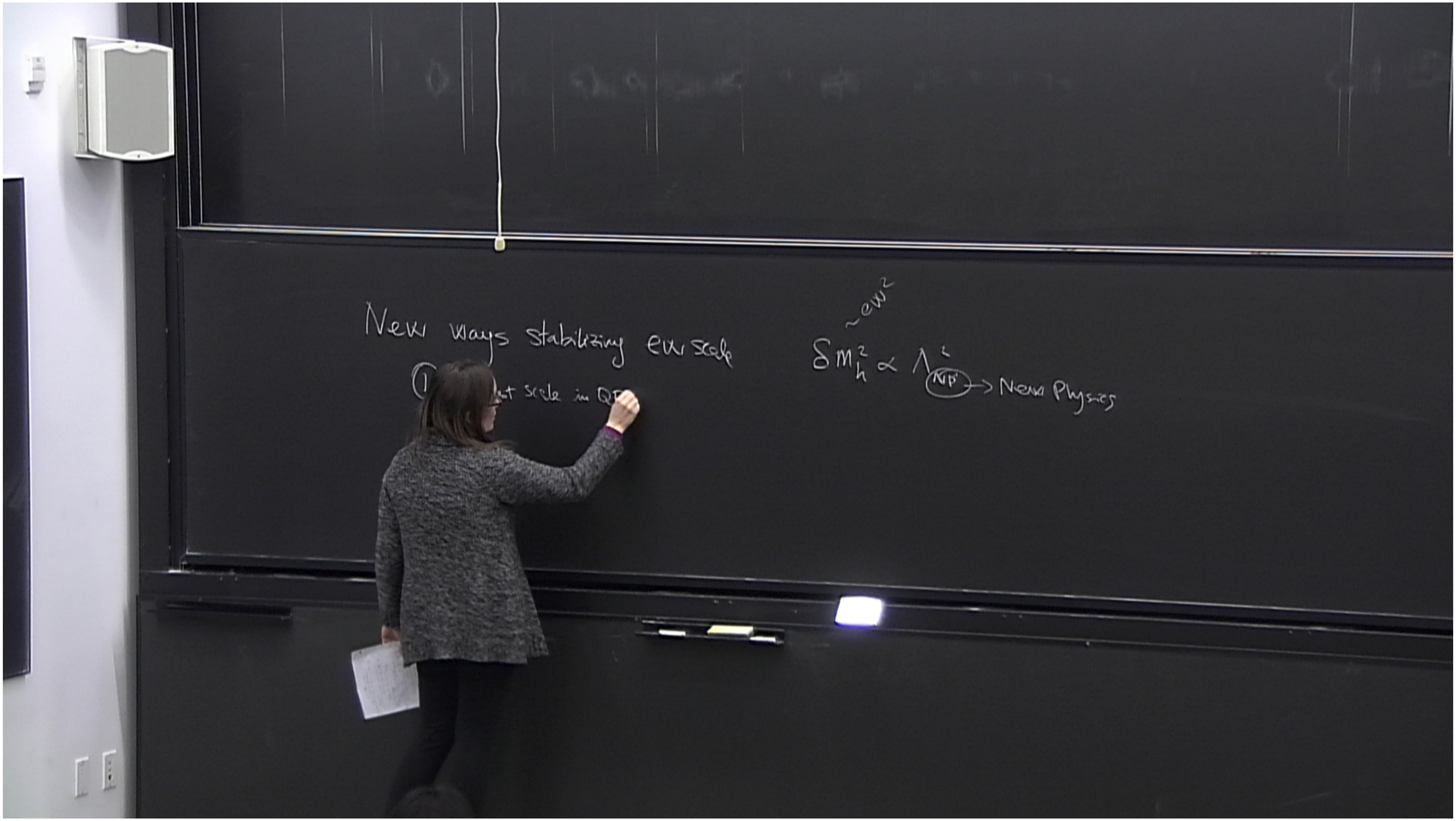

New dimensions of s-t
string thy
spacetime D > 4
↳ test Newtonian dynamics, GR, SR ... 4D → XDIMS hidden → COMPACTIFIED

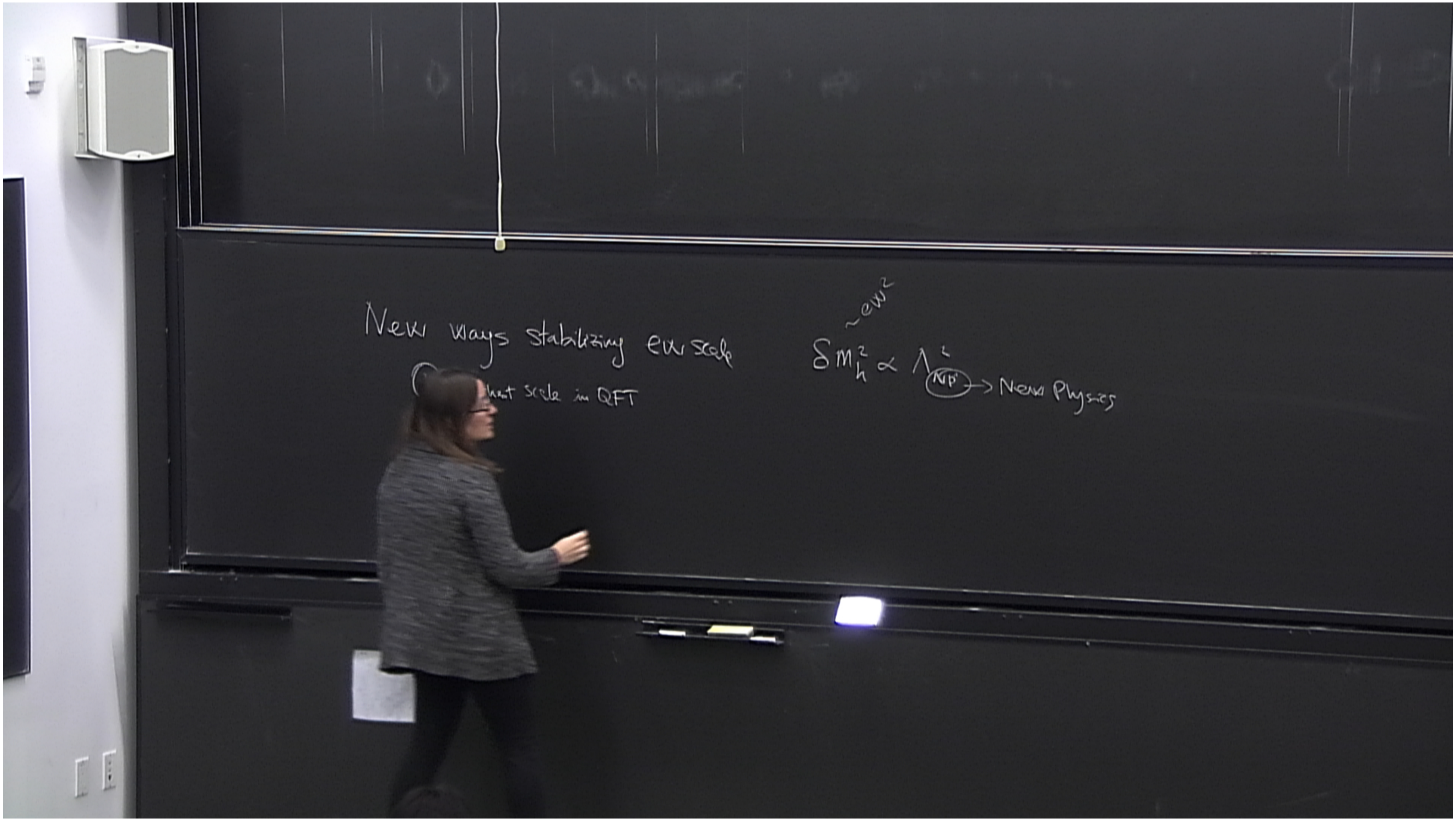

↳ test Newtonian dynamics, GR, SR ... 4D →
vacua ~ 10^500


↳ test Newtonian dynamics, GR, SR ... 4D → X
vacua ~ 10^500
g_μν + h_μν


New dimensions of s-t
↳ test Newtonian dynamics, GR, SR ... 4D → XDIMS hidden → COMPACTIFIED
string thy
spacetime D > 4
vacua ~ 10^500
g_μν + h_μν
XDIMS hologram strongly coupled TC
↳ deconstruction


New ways stabilizing ew scale

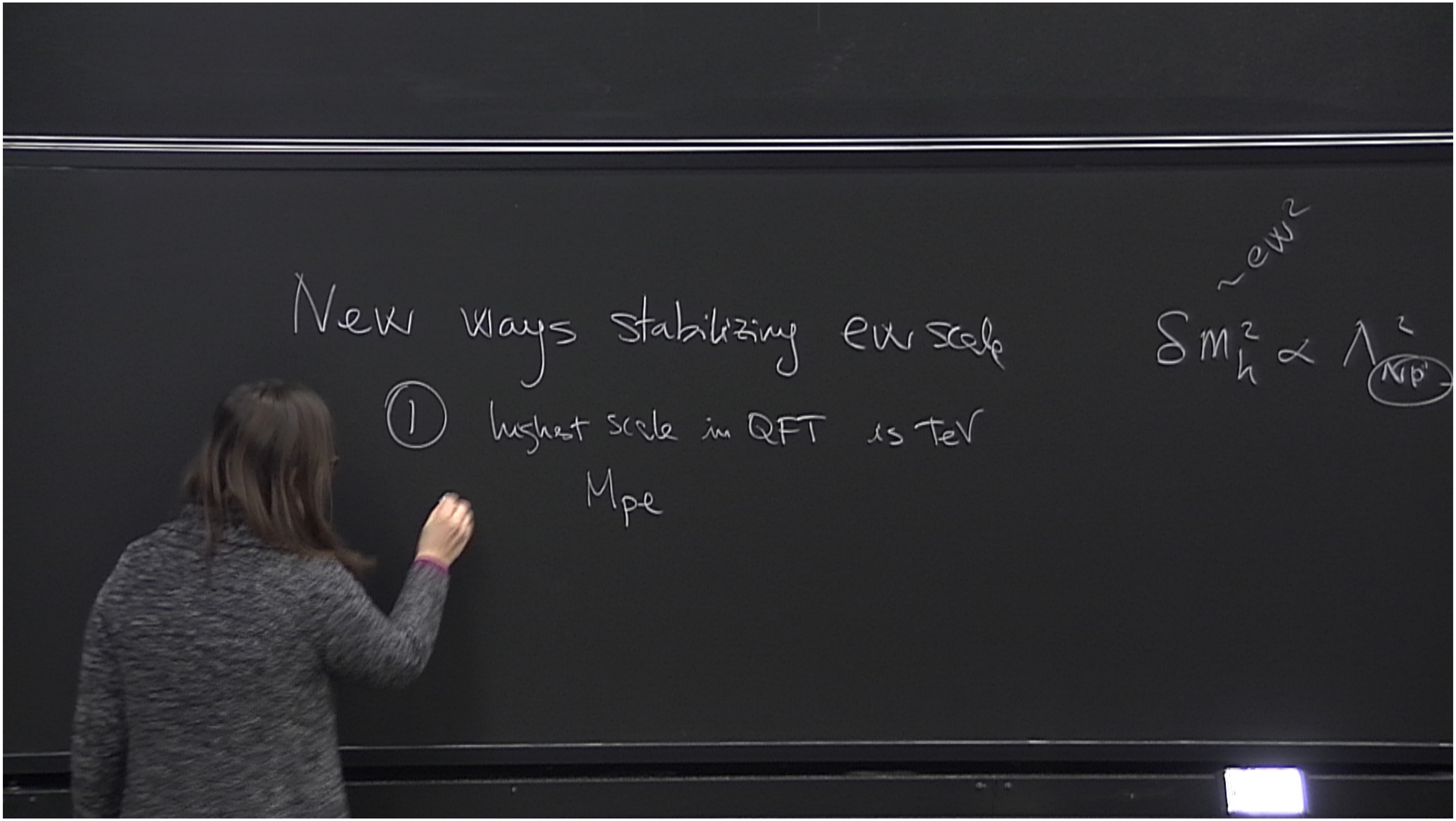

New ways stabilizing ew scale
~ew²
δm²_h ∝ Λ²_NP → New Physics
scale in Q

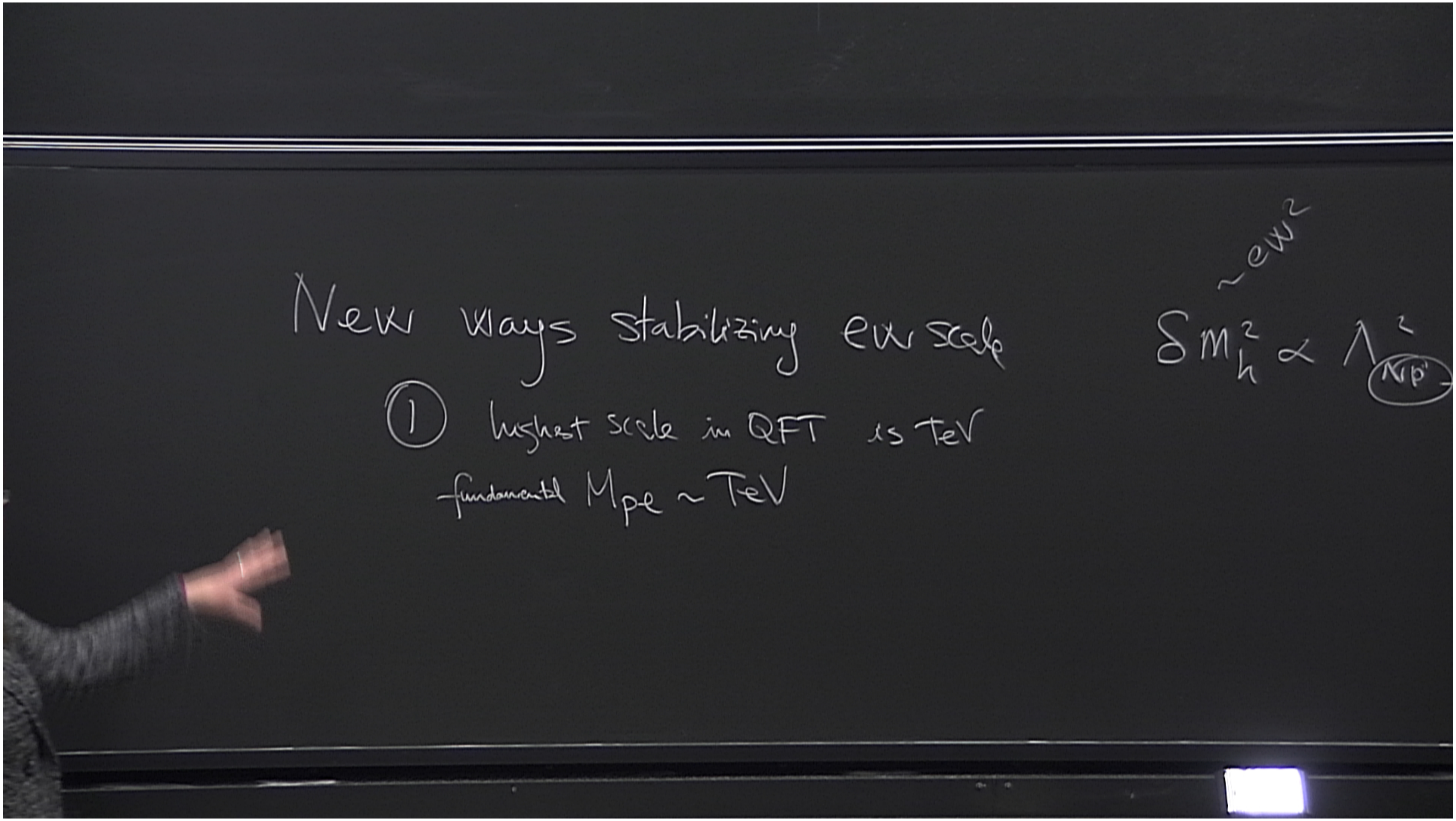

New ways stabilizing ew scale
scale in QFT
~ew²
δm²_h ∝ Λ²
NP → New Physics

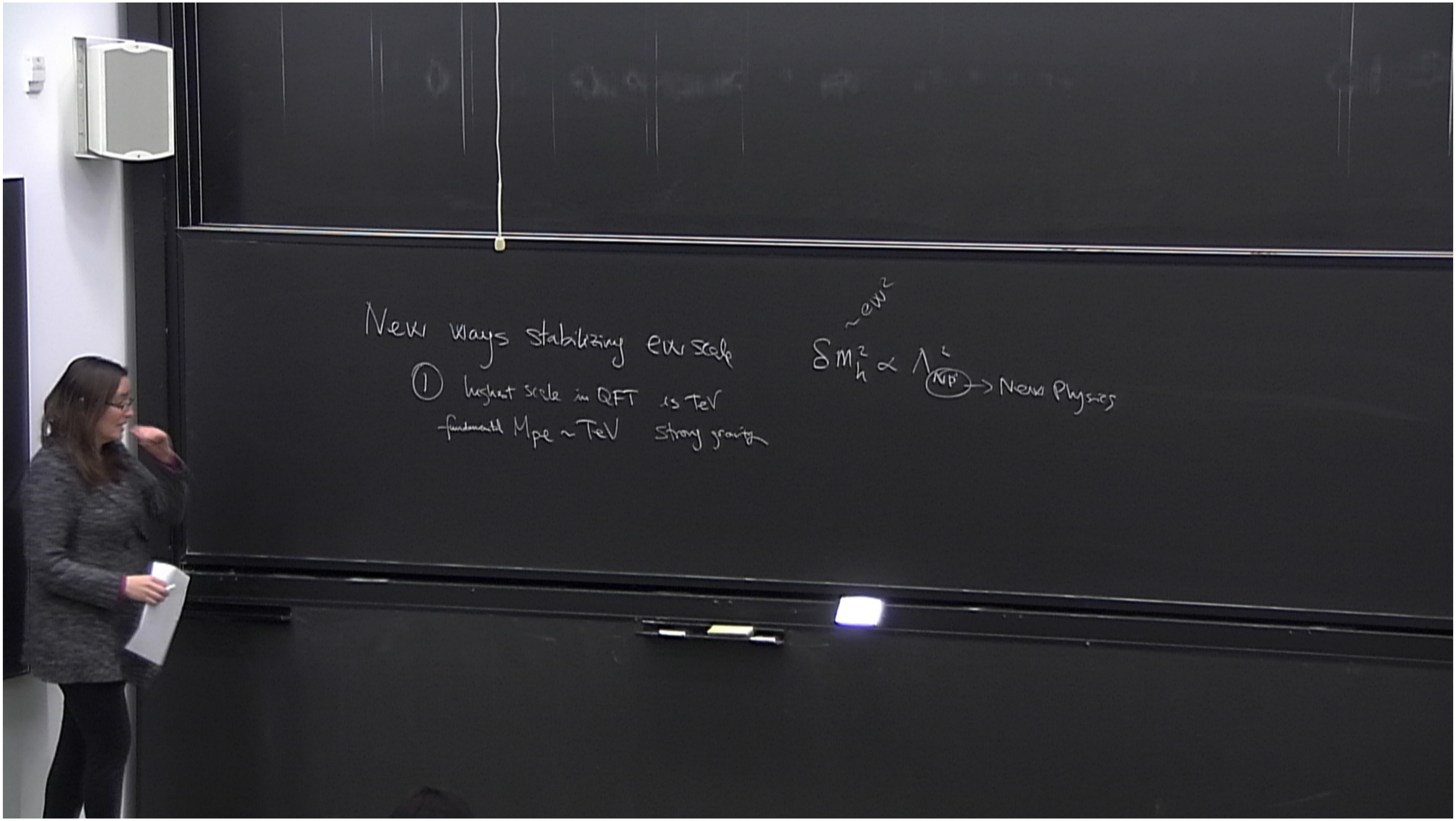
New ways stabilizing ew scale

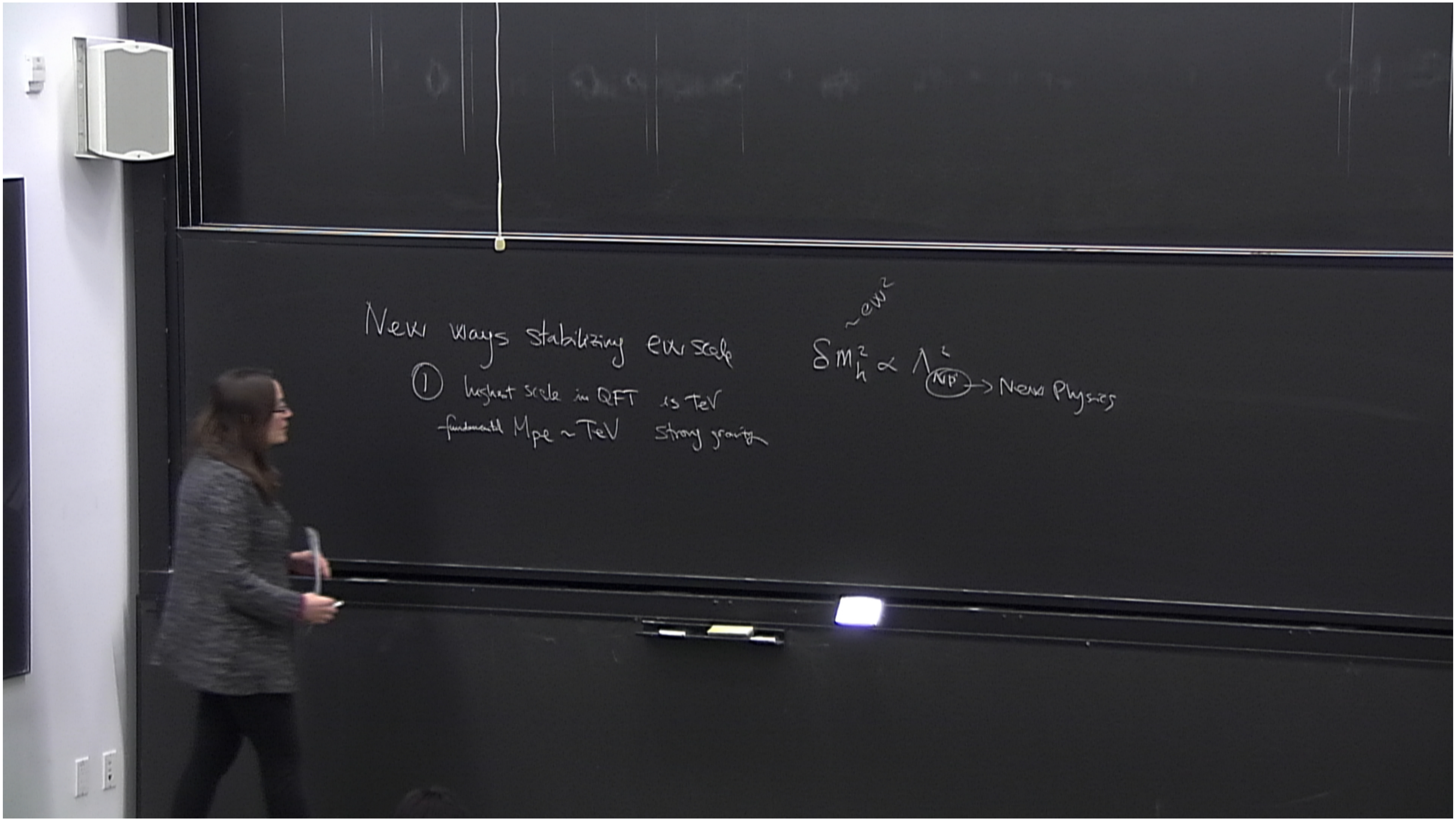
$$\delta m_h^2 \propto \Lambda_{NP}^2 \sim ew^2$$

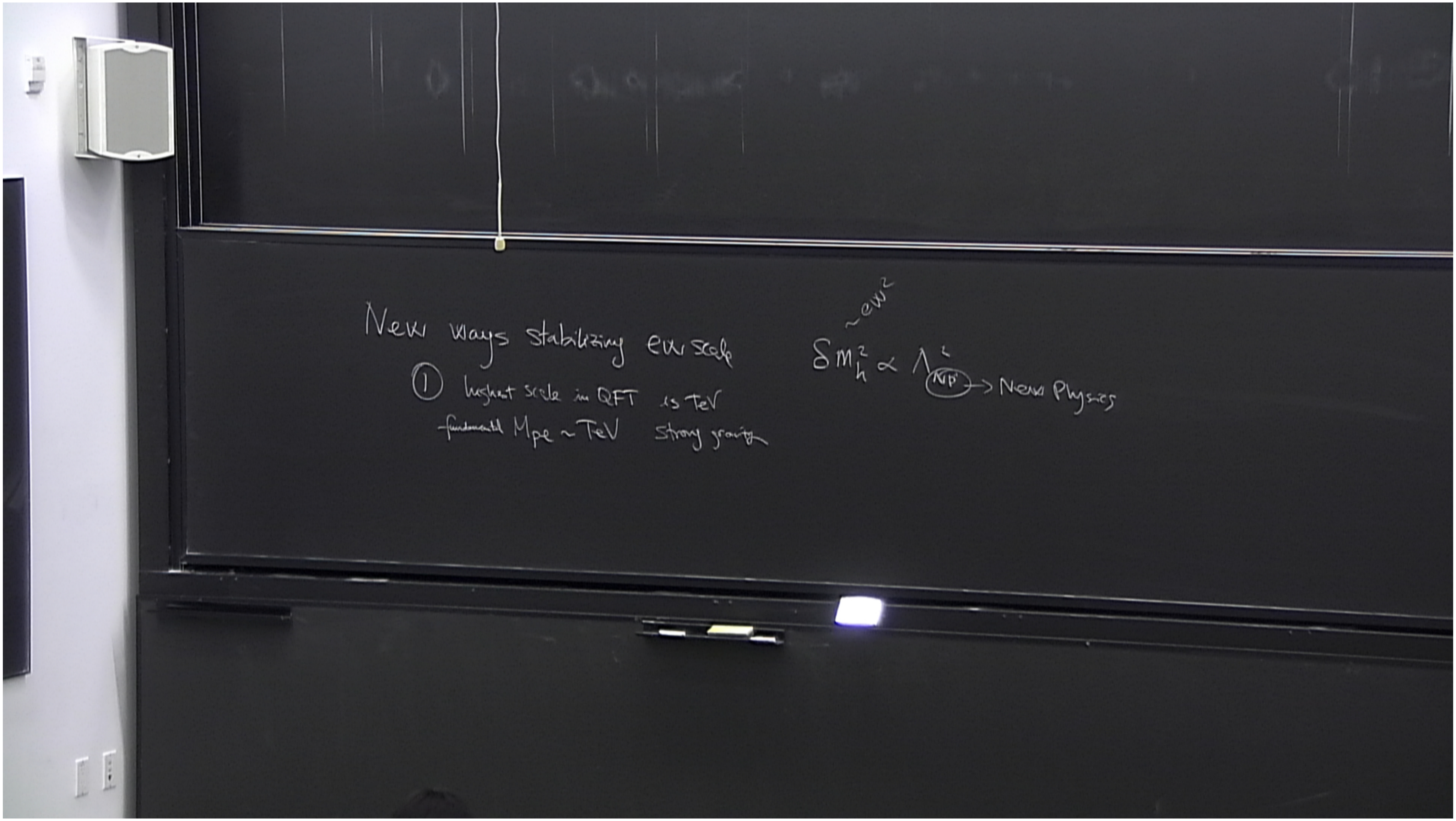
① highest scale in QFT is TeV

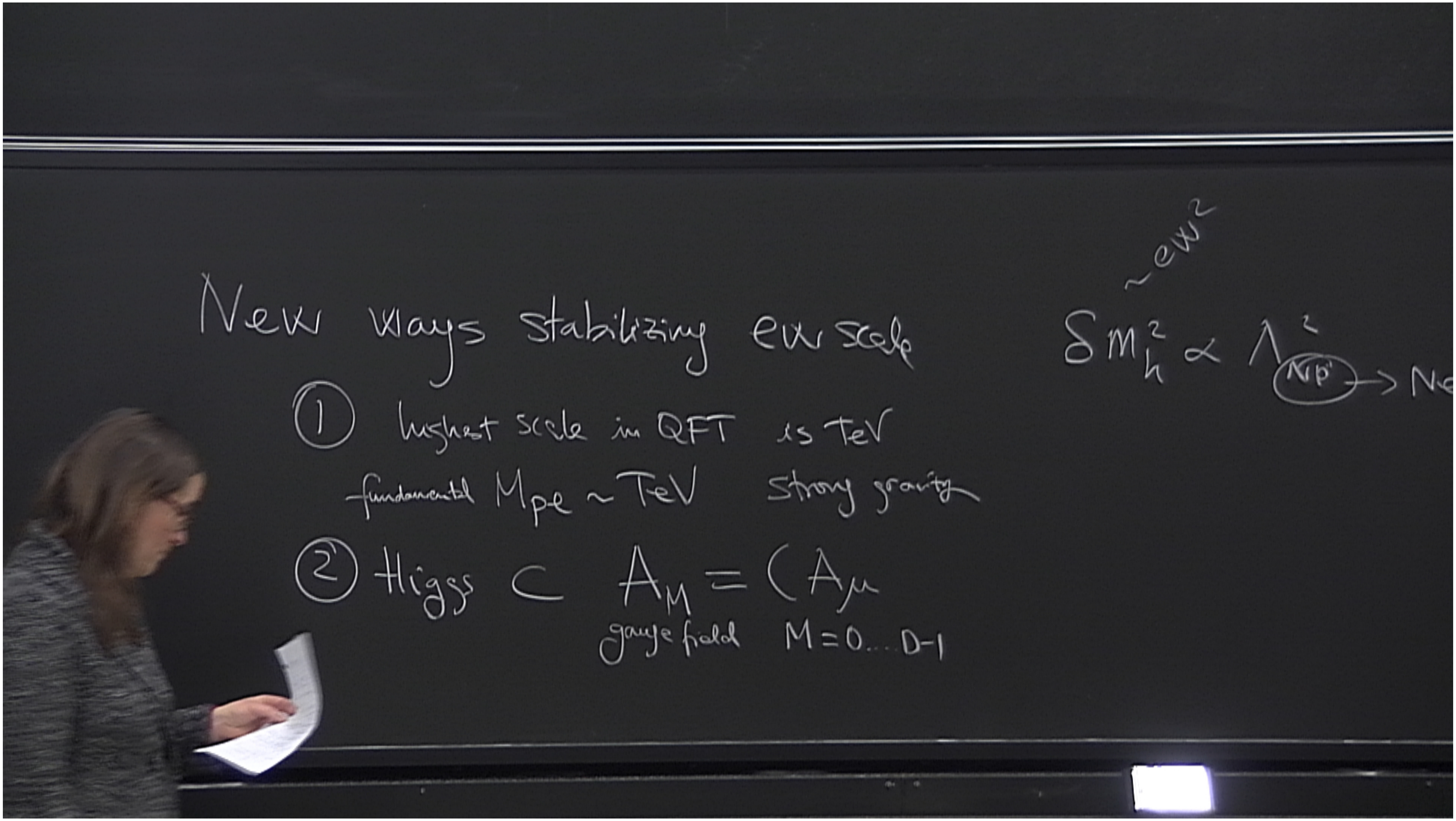

New ways stabilizing ew scale
~ ew²
δm²_h ∝ Λ²_NP
① highest scale in QFT is TeV
M_pl

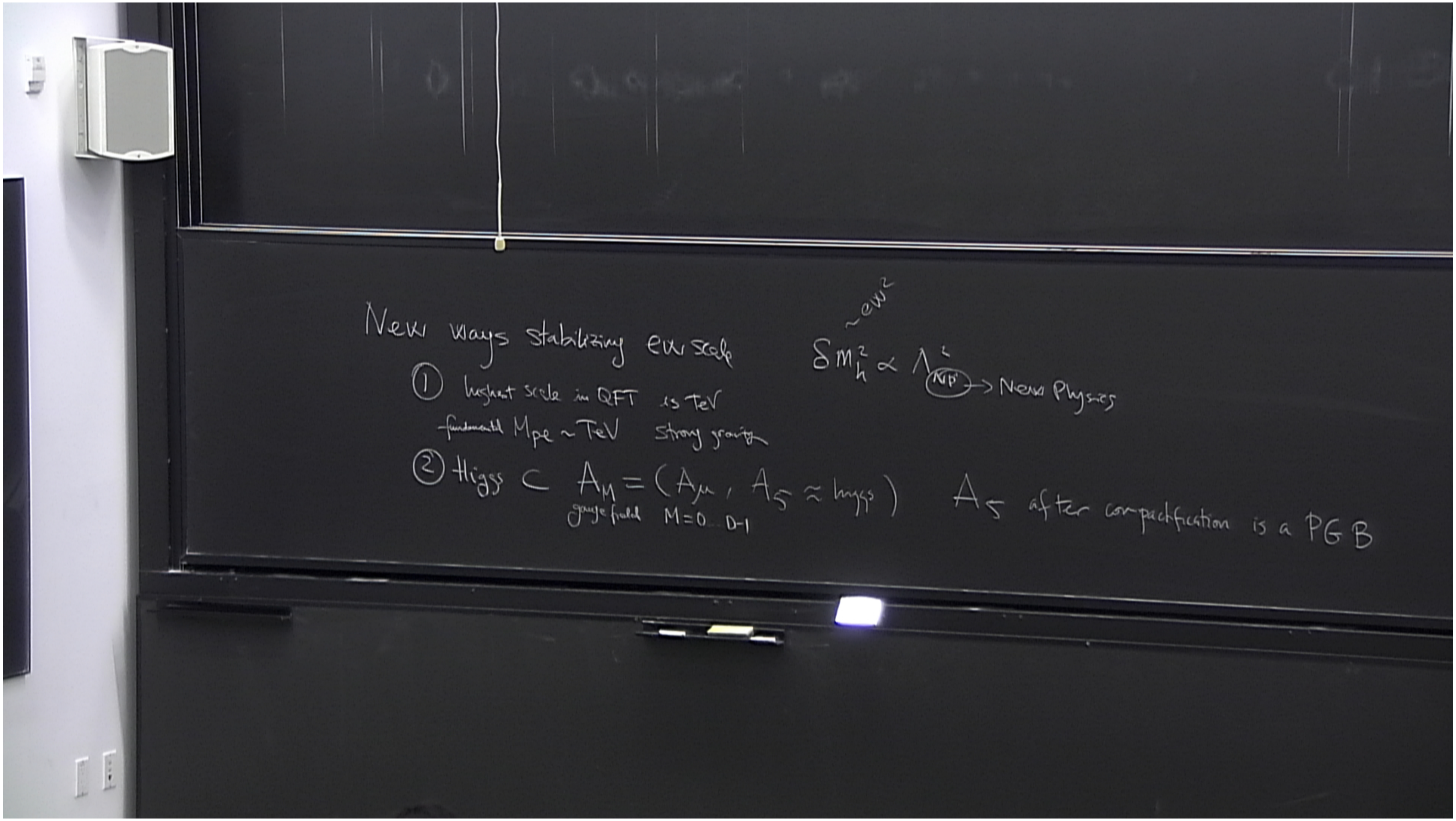

New ways stabilizing ew scale
① highest scale in QFT is TeV
fundamental $M_{pl} \sim$ TeV
$\delta m_h^2 \propto \Lambda_{NP}^2 \sim ew^2$

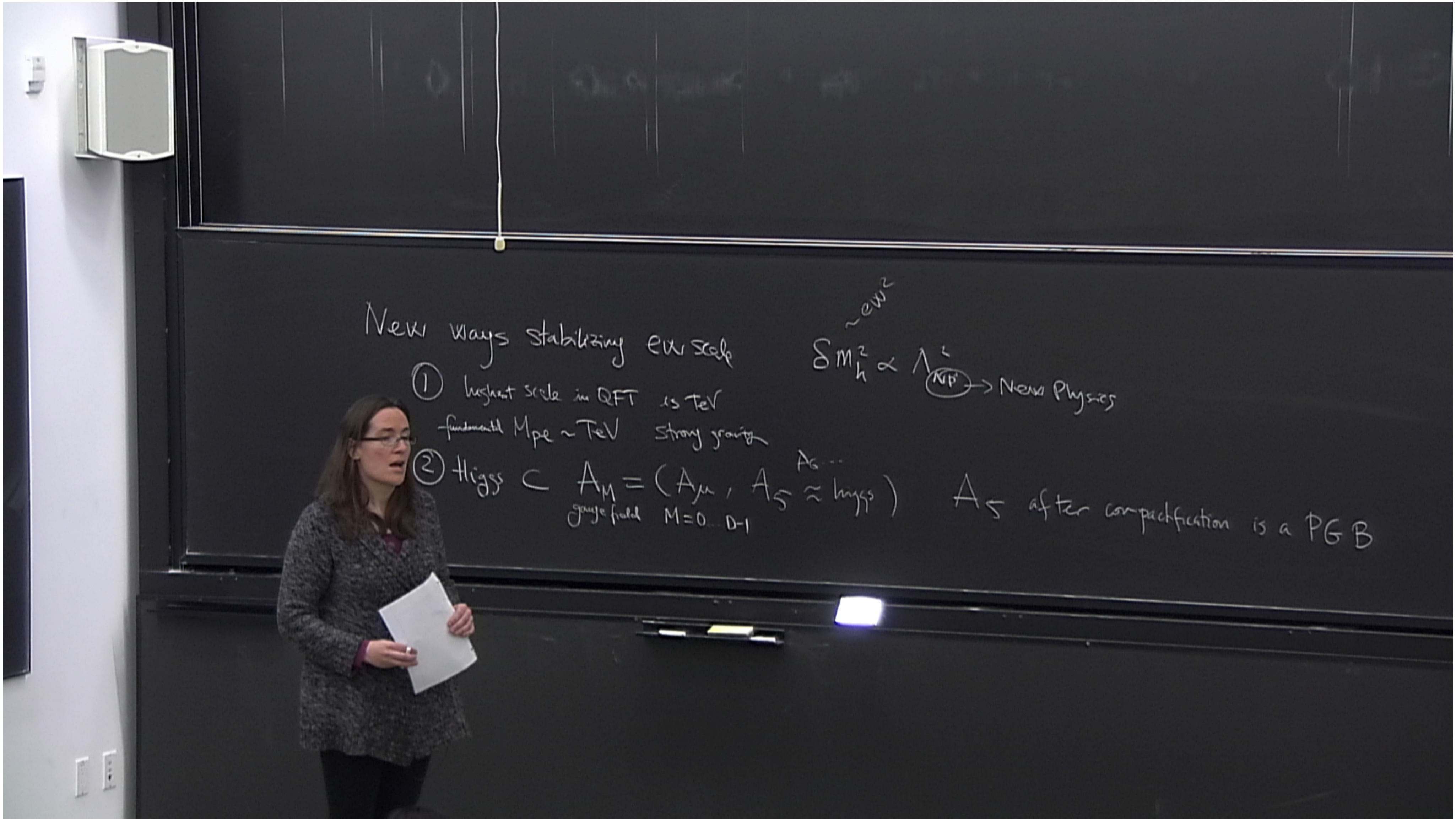

New ways stabilizing ew scale
δm_h^2 ∝ Λ^2_NP → New Physics
~ew^2
① highest scale in QFT is TeV
fundamental M_pl ~ TeV strong gravity

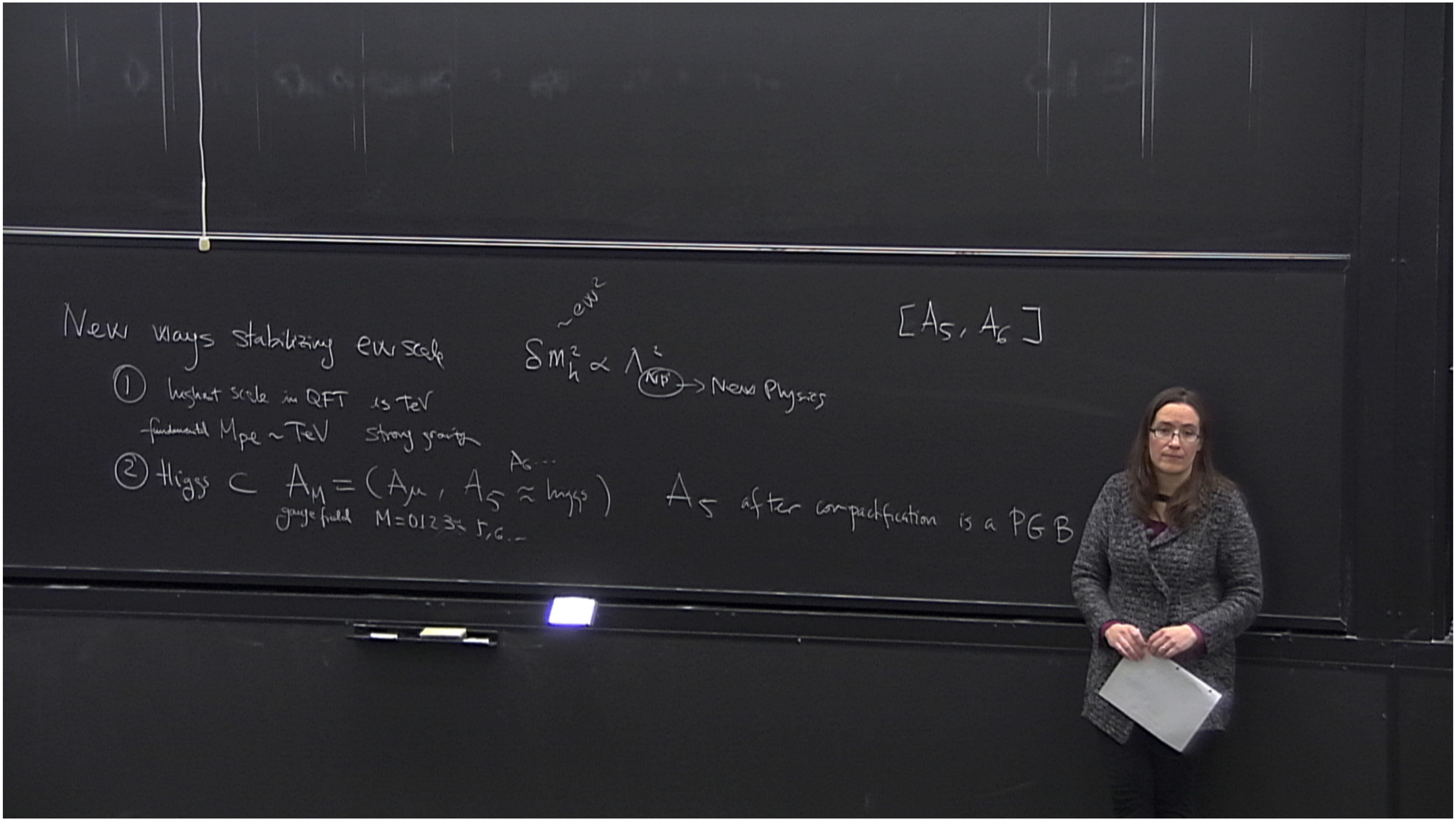

New ways stabilizing ew scale
① highest scale in QFT is TeV
fundamental Mpl ~ TeV strong gravity
~ew²
δm²h ∝ Λ²NP → New Physics

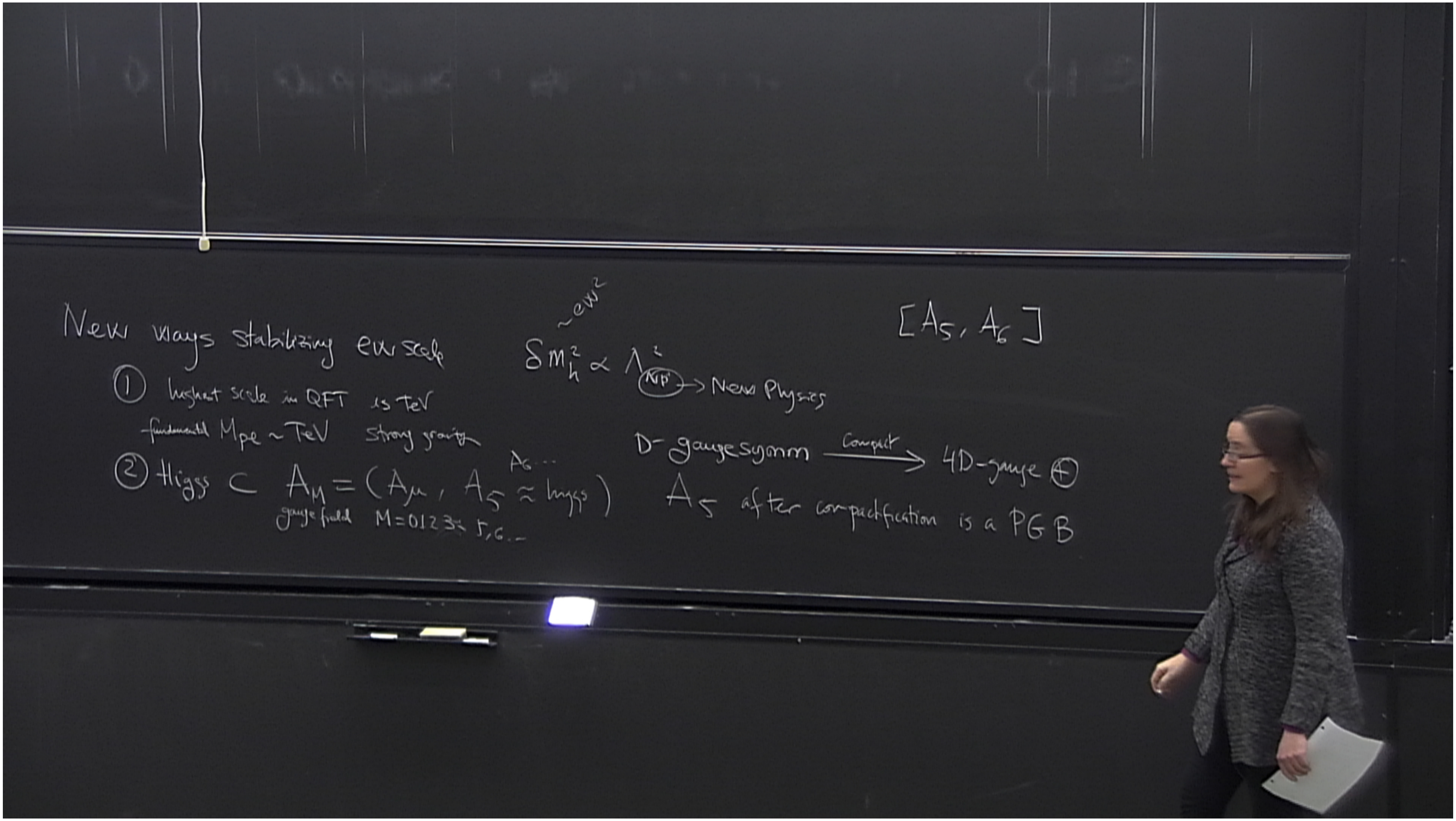

New ways stabilizing ew scale
① highest scale in QFT is TeV
fundamental $M_{pl} \sim$ TeV strong gravity
$\delta m_h^2 \propto \Lambda_{NP}^2 \sim ew^2$
→ New Physics

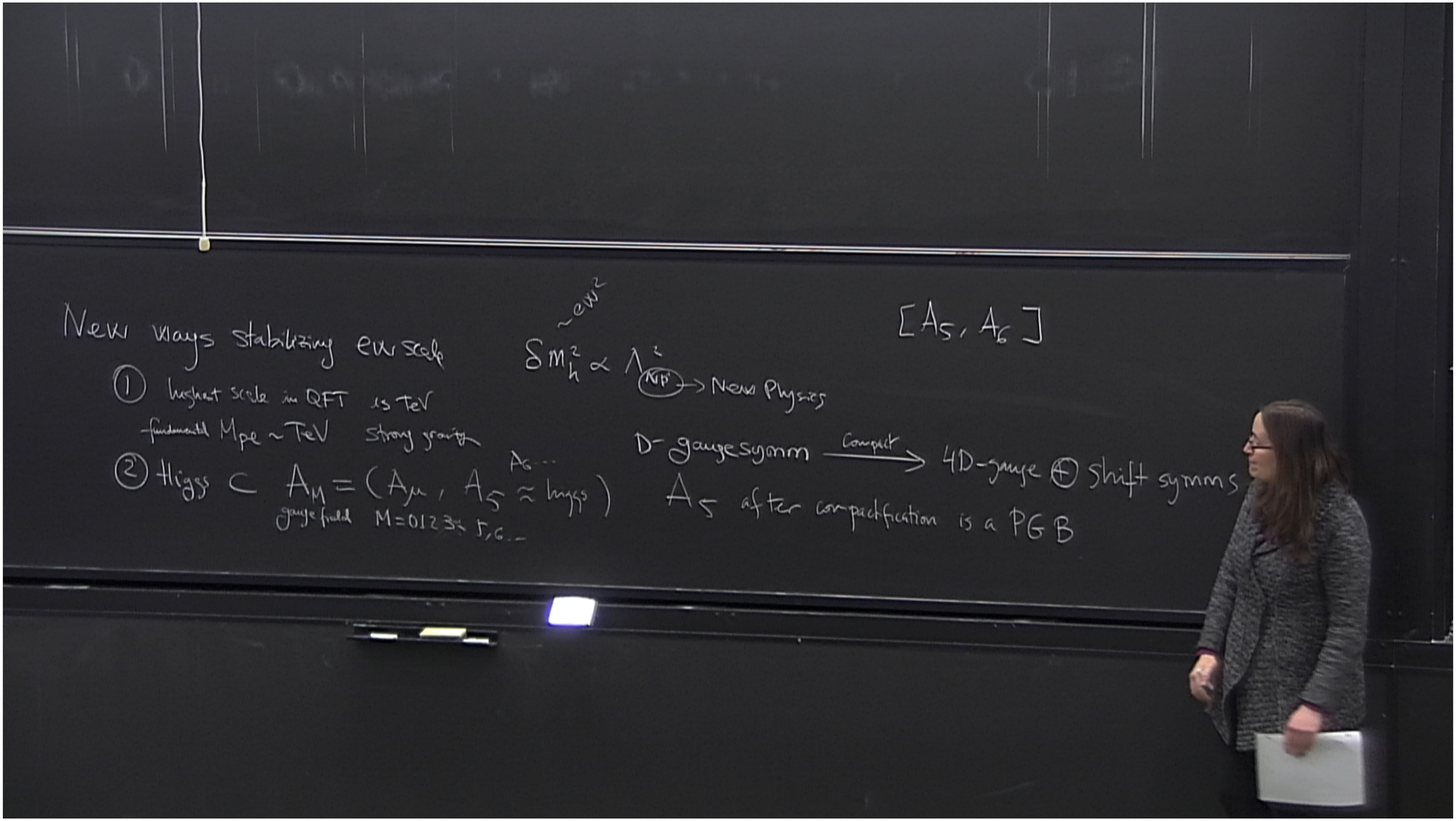

New ways stabilizing ew scale
① highest scale in QFT is TeV
fundamental $M_{pl} \sim$ TeV strong gravity
② Higgs $\subset$ $A_M = (A_\mu$
gauge field $M = 0 \ldots D-1$
$\delta m_h^2 \propto \Lambda^2_{NP} \to$ Ne
$\sim ew^2$

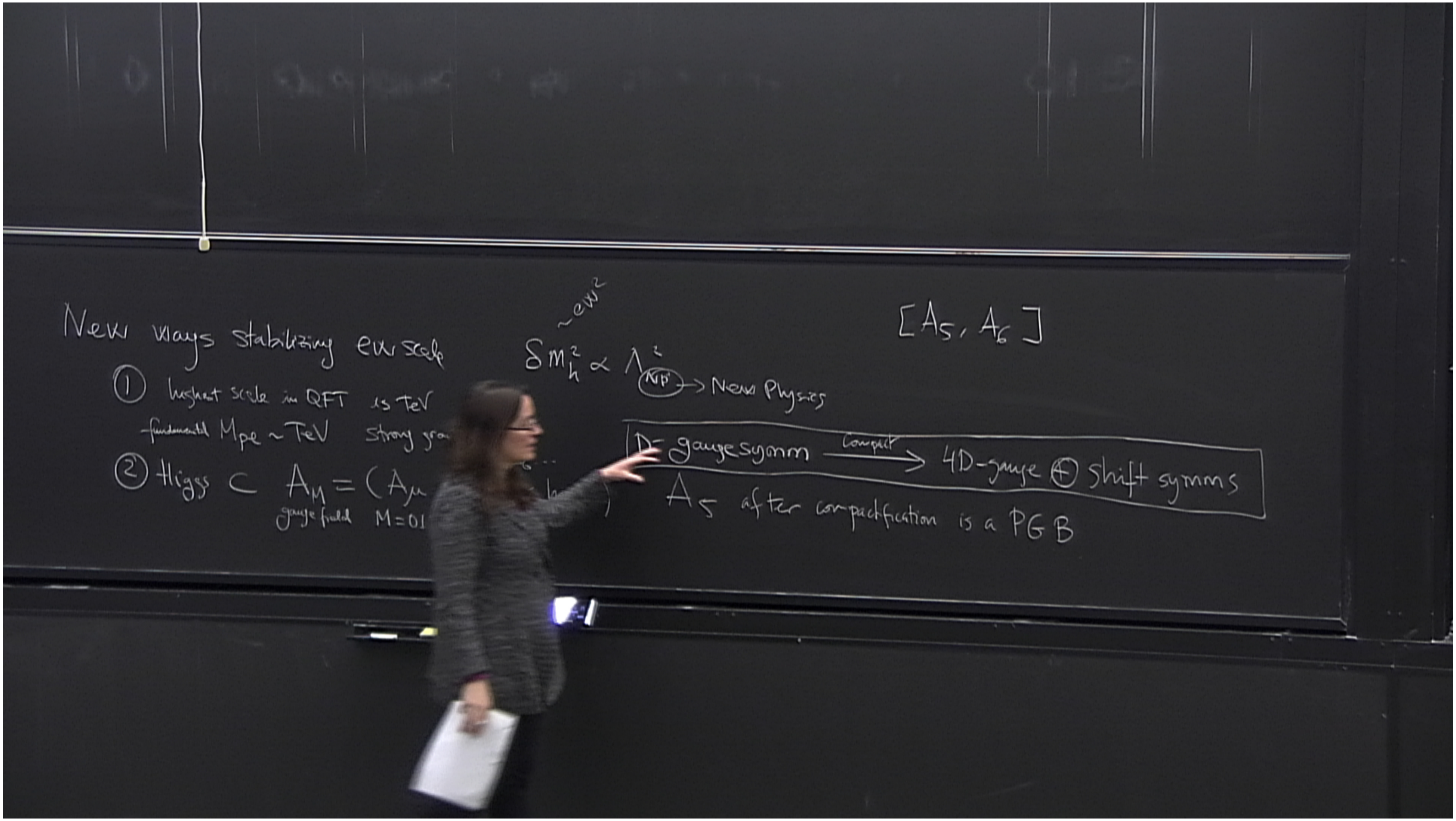

New ways stabilizing ew scale
$\delta m_h^2 \propto \Lambda_{NP}^2$
~ew²
NP → New Physics
① highest scale in QFT is TeV
fundamental $M_{pl} \sim$ TeV strong gravity
② Higgs $\subset A_M = (A_\mu, A_5 \approx$ higgs$)$
gauge field $M = 0 \ldots D-1$
A_5 after compactification is a PGB

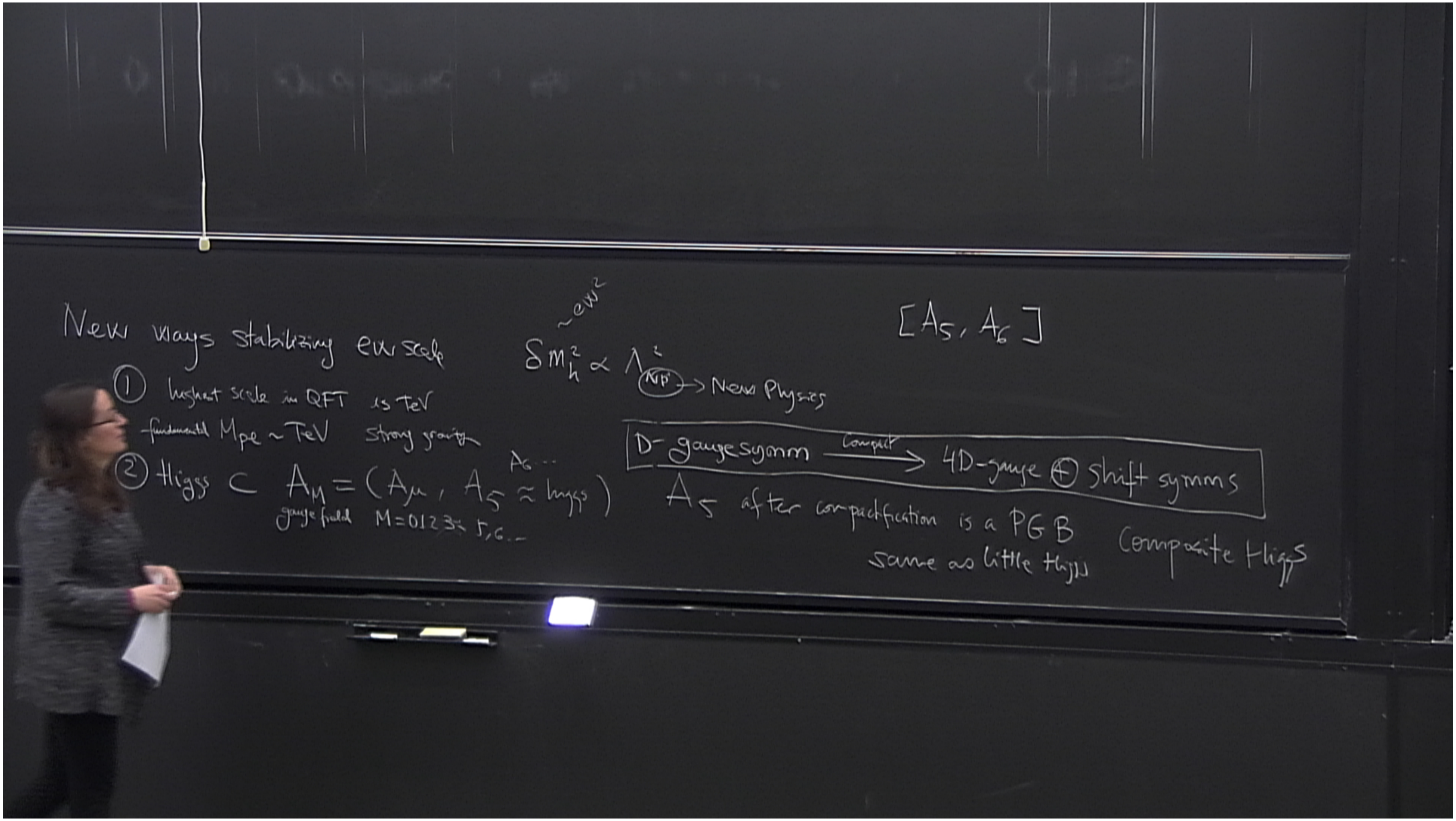

New ways stabilizing ew scale
~ew²
δm_h² ∝ Λ_NP² → New Physics
① highest scale in QFT is TeV
fundamental M_pl ~ TeV   strong gravity
A_6 ...
② Higgs ⊂ A_M = (A_μ , A_5 ≈ higgs)
gauge field   M=0...D-1
A_5 after compactification is a PGB


New ways stabilizing ew scale
~ew²
δm²_h ∝ Λ²_NP
NP → New Physics
[A5, A6]
① highest scale in QFT is TeV
fundamental Mpl ~ TeV strong gravity
② Higgs ⊂ A_M = (A_μ, A_5 ≈ higgs)
A6 ...
gauge field M = 0123, 5, 6 ...
A5 after compactification is a PGB


New ways stabilizing ew scale
① highest scale in QFT is TeV
fundamental Mpl ~ TeV strong gravity
② Higgs ⊂ A_M = (A_μ, A_5 ≈ higgs)
A_6 ...
gauge field M=0123, 5,6...
δm_h^2 ∝ Λ_NP^2
~ew^2
NP → New Physics
[A_5, A_6]
D-gauge symm → 4D-gauge ⊕
compact
A_5 after compactification is a PGB


New ways stabilizing ew scale
$\delta m_h^2 \propto \Lambda_{NP}^2$ ~ew²
→ New Physics
[A5, A6]
① highest scale in QFT is TeV
fundamental Mpe ~ TeV strong gravity
② Higgs ⊂ $A_M = (A_\mu, A_5 \approx \text{higgs})$
gauge field M=0123, 5, 6...
A6...
D-gauge symm —Compact→ 4D-gauge ⊕ shift symms
A5 after compactification is a PGB


New ways stabilizing ew scale
① highest scale in QFT is TeV
fundamental Mpe ~ TeV strong gra
② Higgs ⊂ A_M = (A_μ
gauge field M = 01
δm_h^2 ∝ Λ^2
~ew^2
NP → New Physics
D- gauge symm
compact
4D-gauge ⊕ shift symms
A_5 after compactification is a PGB
[A_5, A_6]

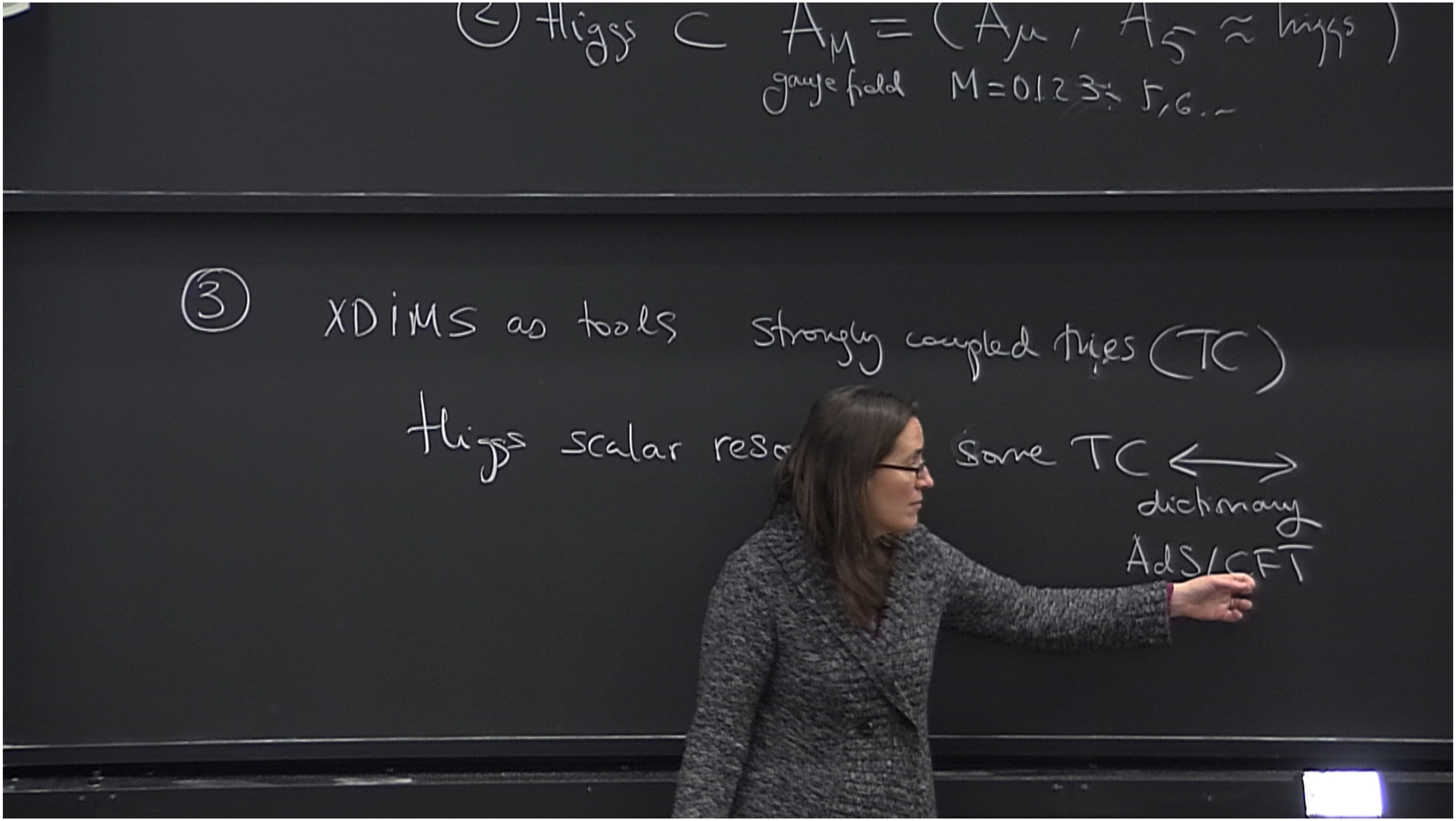

New ways stabilizing ew scale
① highest scale in QFT is TeV
fundamental Mpe ~ TeV strong gravity
② Higgs ⊂ A_M = (A_μ, A_5 ≈ higgs)
gauge field M = 0123, 5, 6 ...
A_6 ...
δm_h^2 ∝ Λ_NP^2 ~ ew^2
NP → New Physics
[A_5, A_6]
D-gauge symm → compact → 4D-gauge ⊕ shift symms
A_5 after compactification is a PGB
same as little Higgs
Composite Higgs

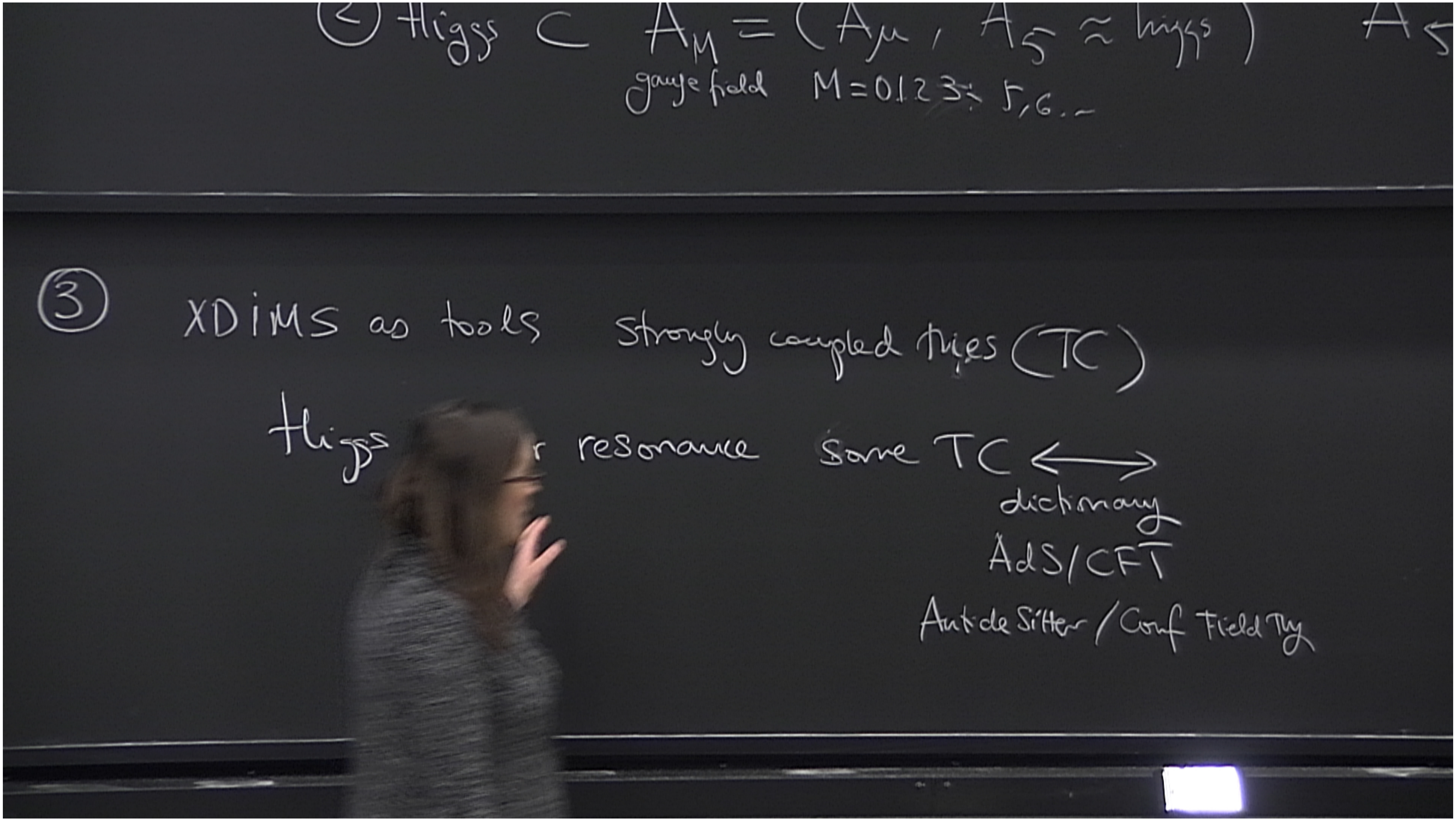
② Higgs $\subset$ $A_M = (A_\mu\,,\ A_5 \approx \text{higgs})$

gauge field $M = 0\,1\,2\,3\,;\ 5, 6 \ldots$

③ XDIMS as tools strongly coupled thies (TC)

Higgs scalar resonance some TC


② Higgs ⊂ A_M = (A_μ, A_5 ≈ higgs)
gauge field M = 0 1 2 3; 5, 6 ...
③ XDIMS as tools strongly coupled thies (TC)
Higgs scalar reso
some TC ⟷
dictionary
AdS/CFT



② Higgs ⊂ $A_M = (A_\mu, A_5 \approx$ higgs$)$ A_5
gauge field $M = 0 1 2 3 ; 5, 6 \ldots$
③ XDIMS as tools strongly coupled thies (TC)
Higgs r resonance some TC $\longleftrightarrow$
dictionary
AdS/CFT
Anti de Sitter / Conf Field Thy

② Higgs $\subset$ $A_M = (A_\mu, A_5 \approx \text{higgs})$ A_5

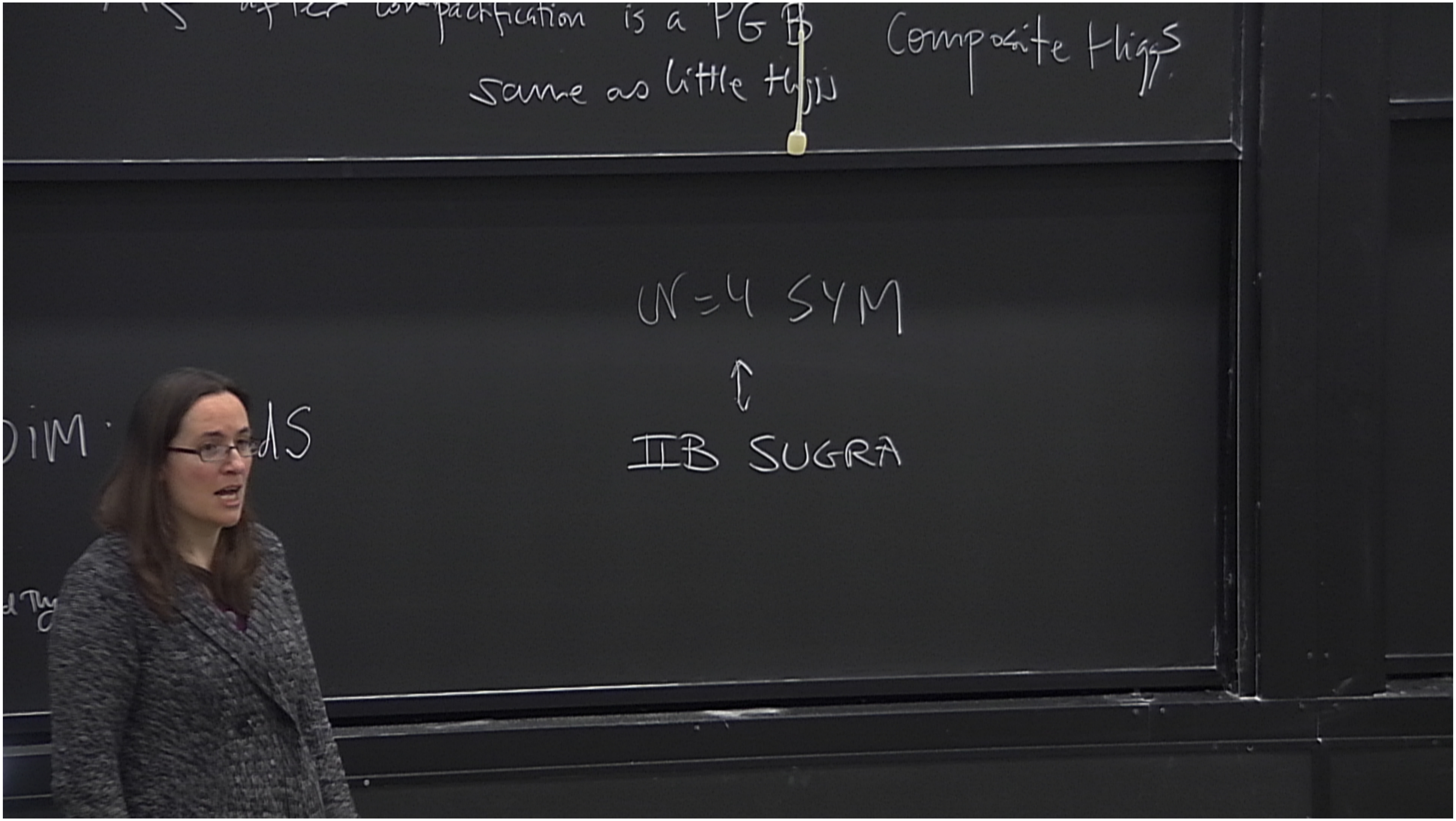
gauge field $M = 0123 ; 5, 6 \ldots$

③ XDIMS as tools strongly coupled thies (TC)

Higgs scalar resonance some TC $\xleftrightarrow[\text{dictionary}]{}$ XDIM in

AdS/CFT

Anti de Sitter / Conf Field Thy



compactification is a PGB
same as little Higgs
Composite Higgs
N=4 SYM
IIB SUGRA

(1) highest scale in QFT is TeV

fundamental $M_{pl} \sim$ TeV strong gravity

(2) Higgs $\subset$ $A_M = (A_\mu, A_5 \approx \text{higgs})$ $A_6 \ldots$

gauge field $M = 0123, 5, 6 \ldots$

NP $\to$ New Physics

$\boxed{\text{D-gauge symm} \xrightarrow{\text{compact}} \text{4D-gauge} \oplus \text{shift symms}}$

A_5 after compactification is a PGB

same as little Higgs

Composite Higgs

XDIMS as tools strongly coupled theories (TC)

Higgs scalar resonance Some TC $\xleftrightarrow{\text{dictionary}}$ XDIM in AdS

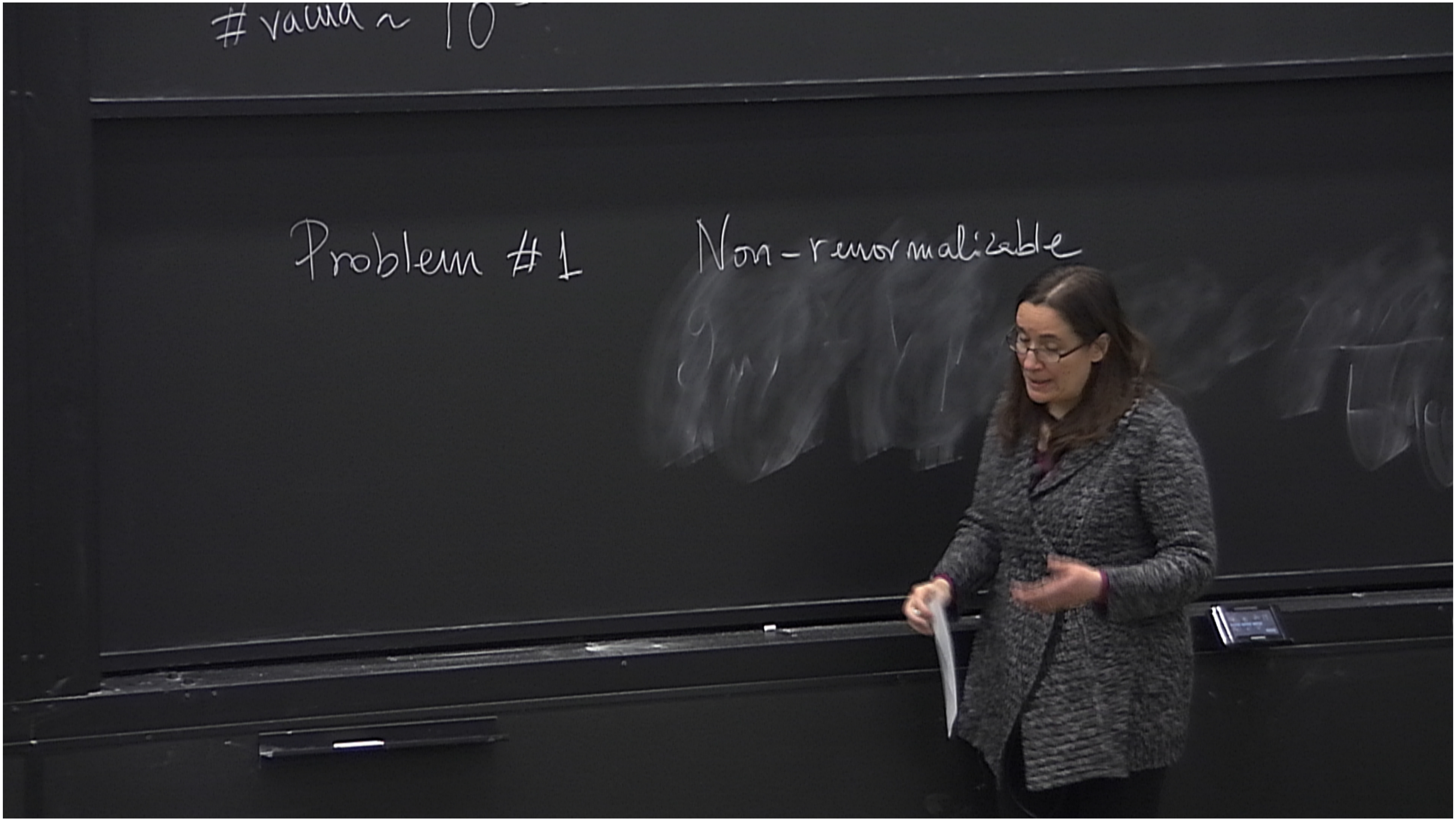
AdS/CFT $\oplus$

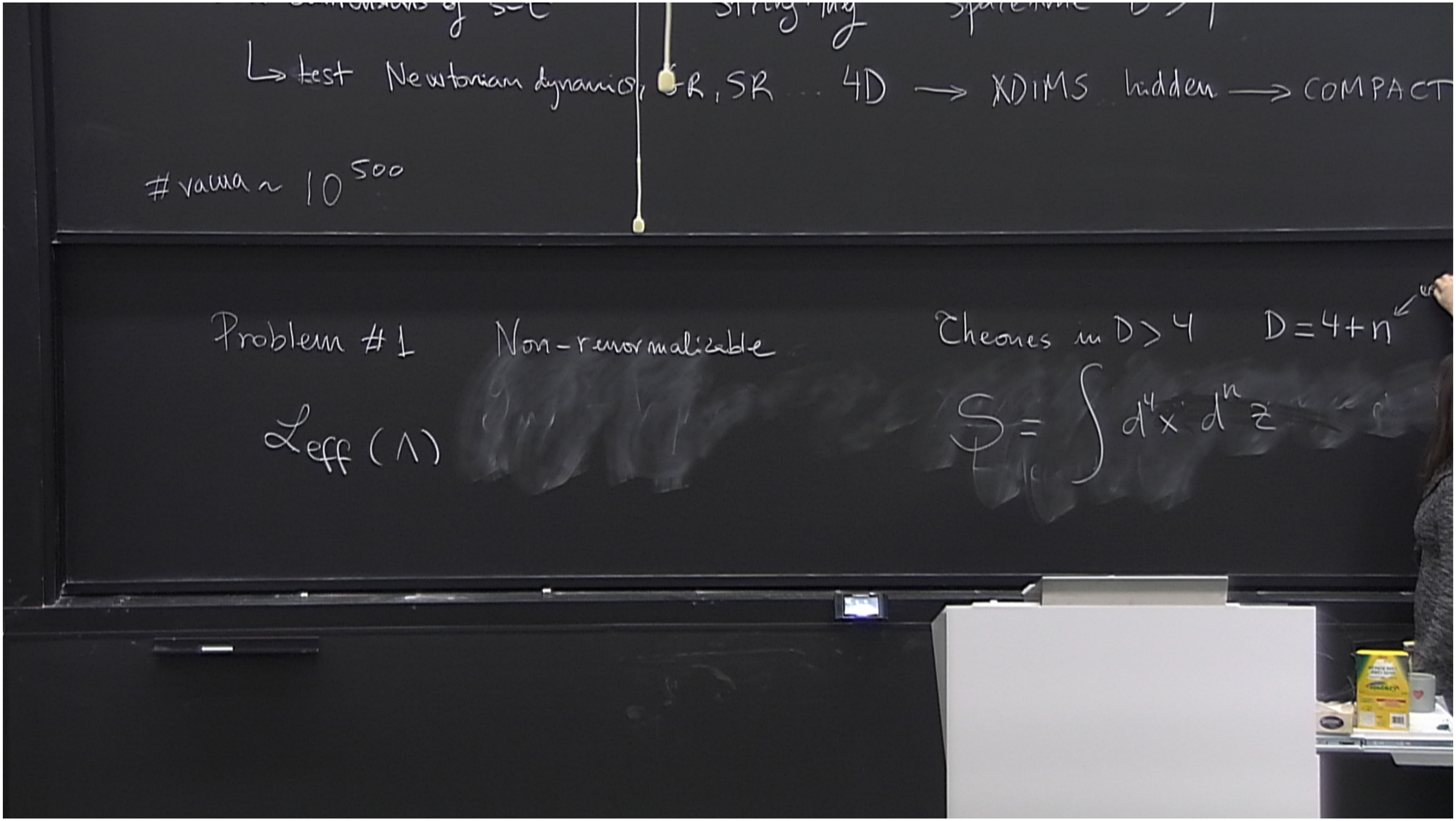
Anti de Sitter / Conf Field Thy

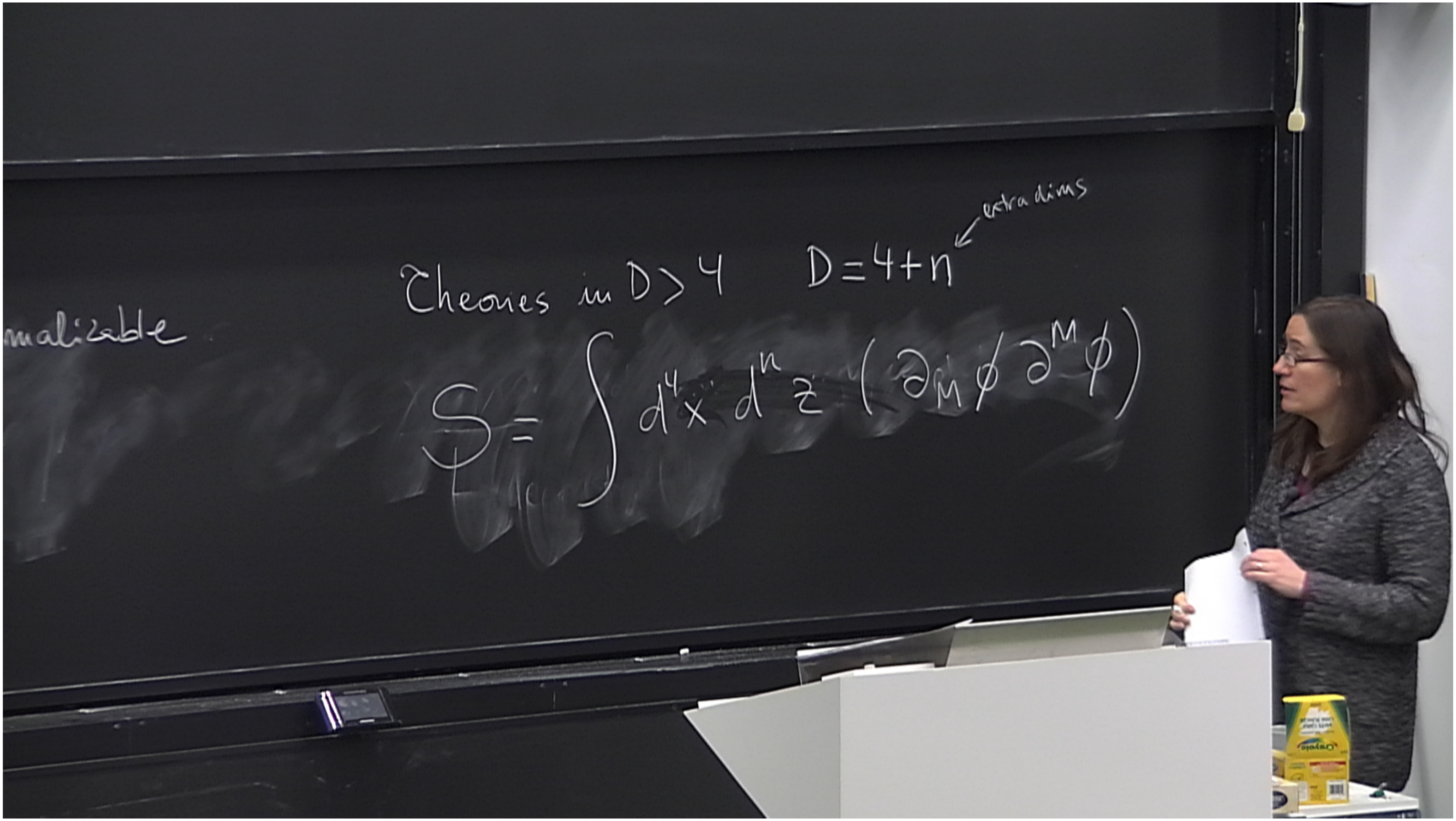
$\mathcal{N}=4$ SYM

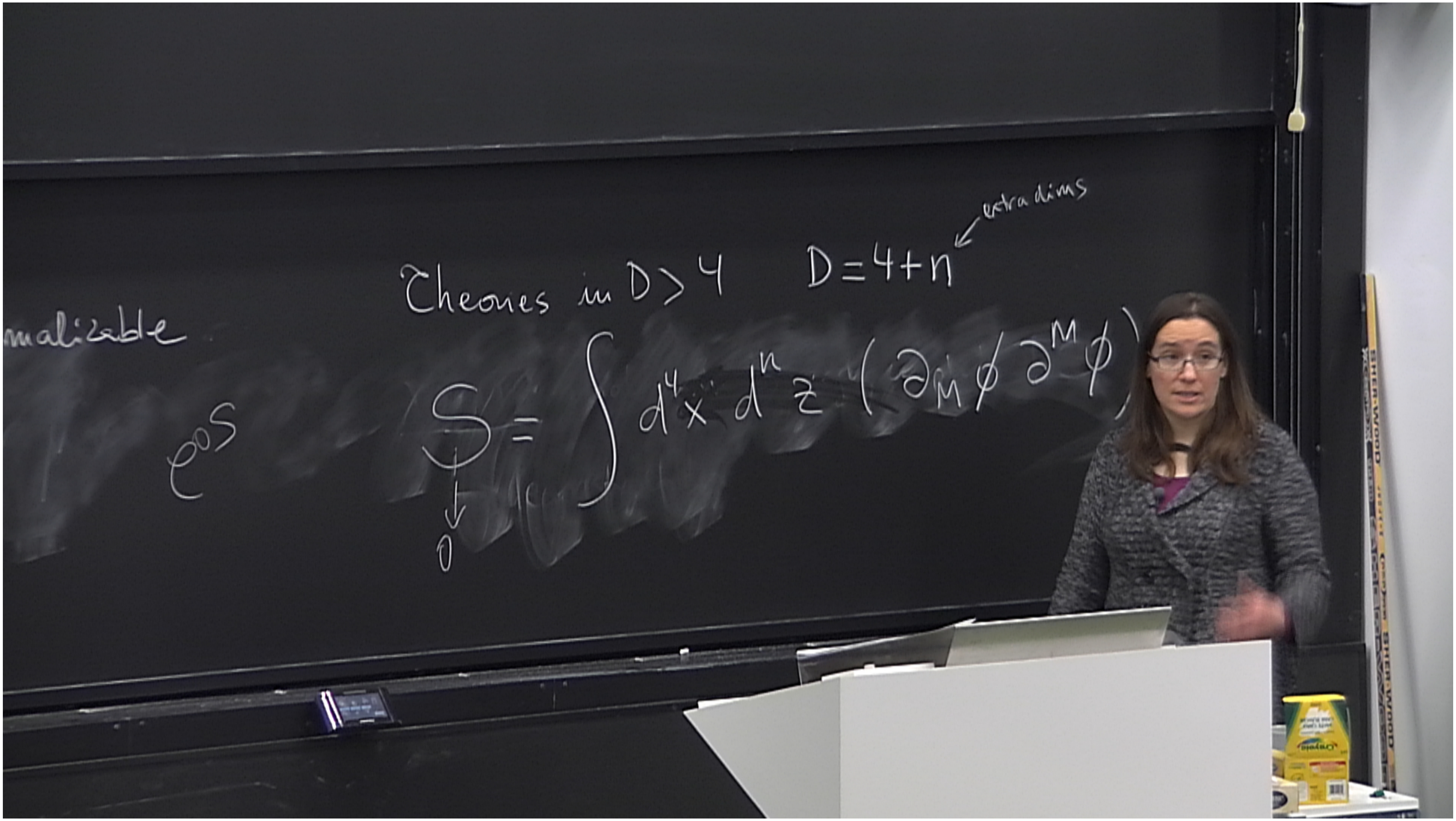
$\updownarrow$

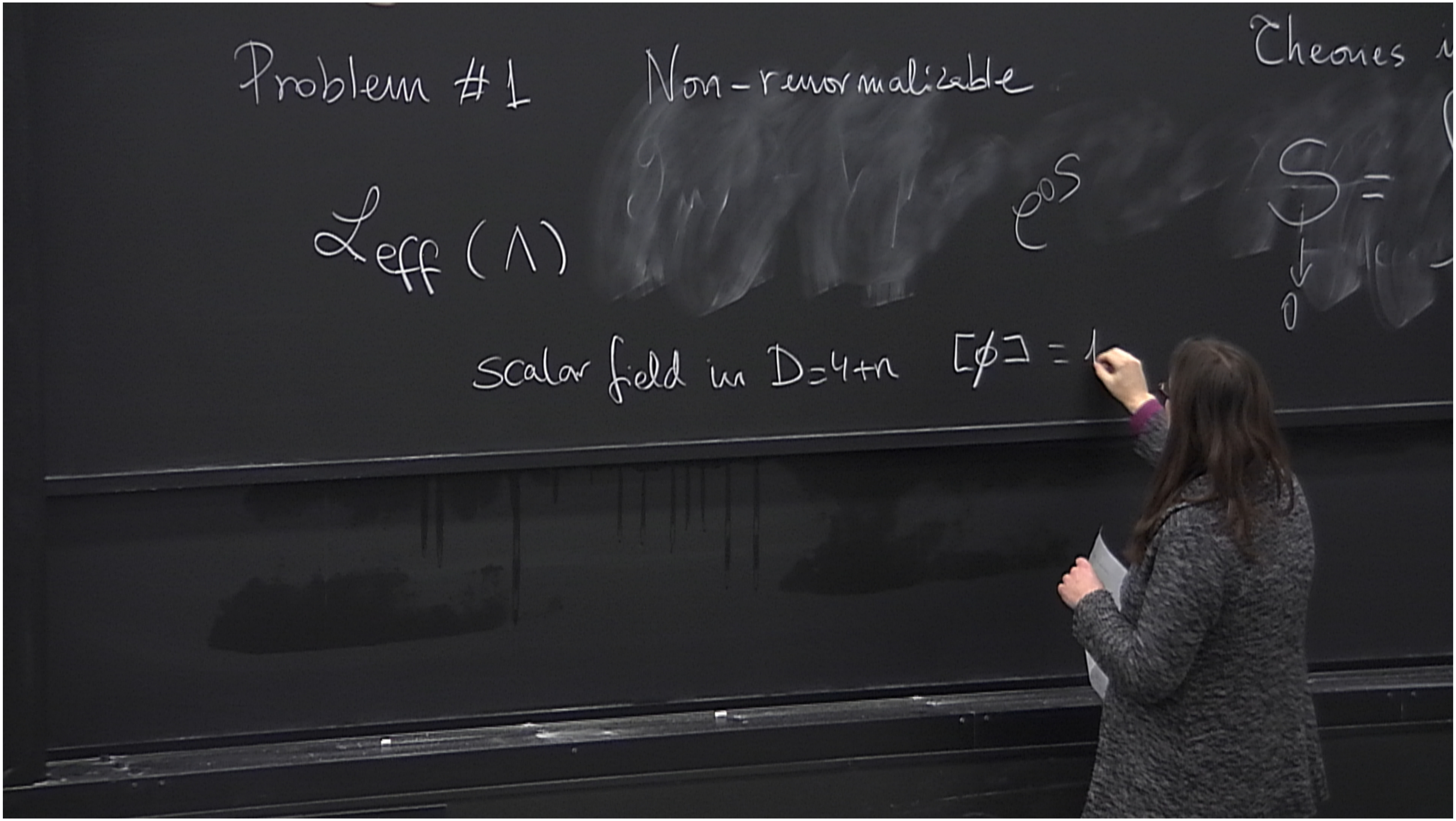
IIB SUGRA $AdS_5 \times S^5$

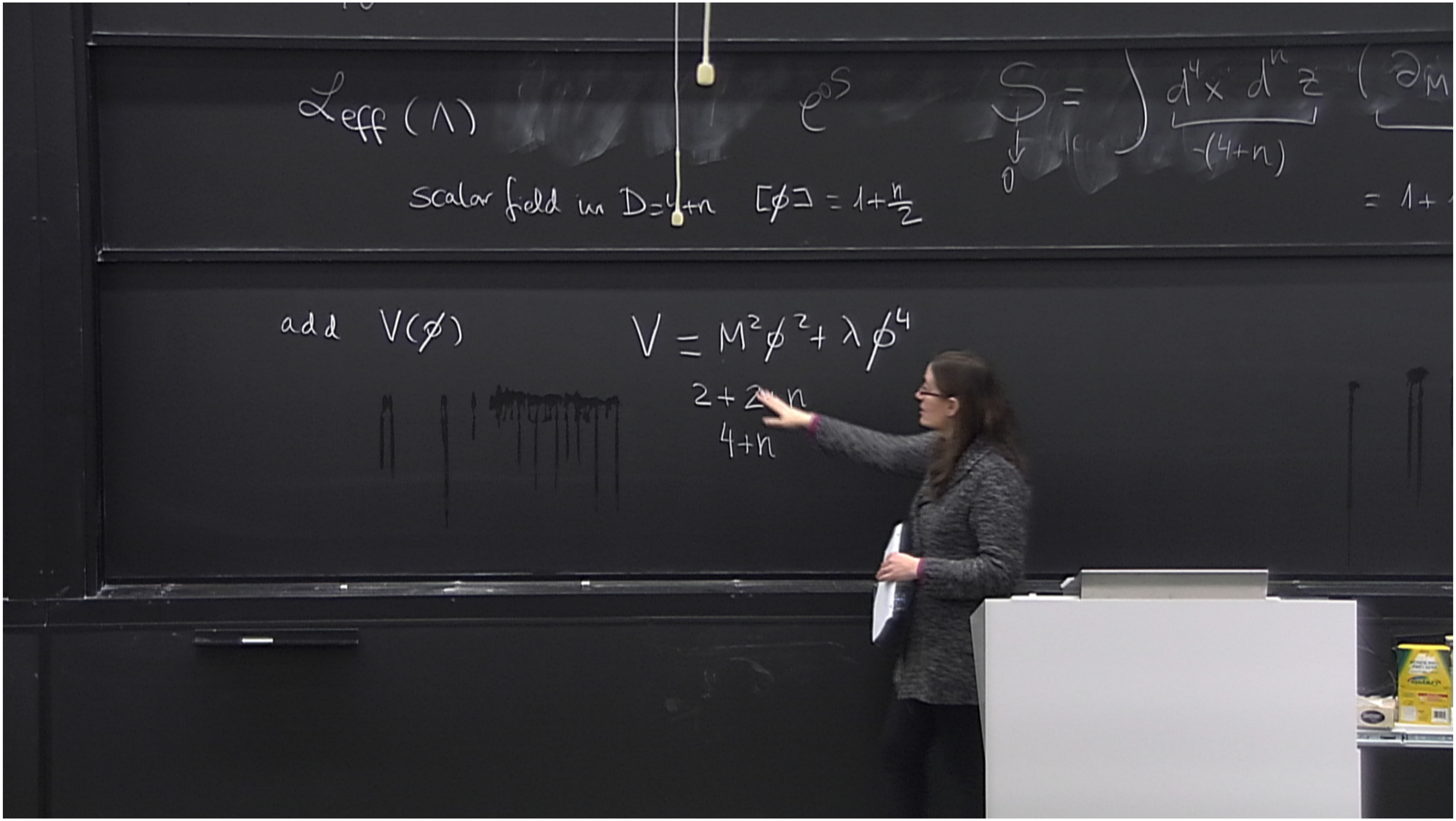

Problem #1
Non-renormalizable

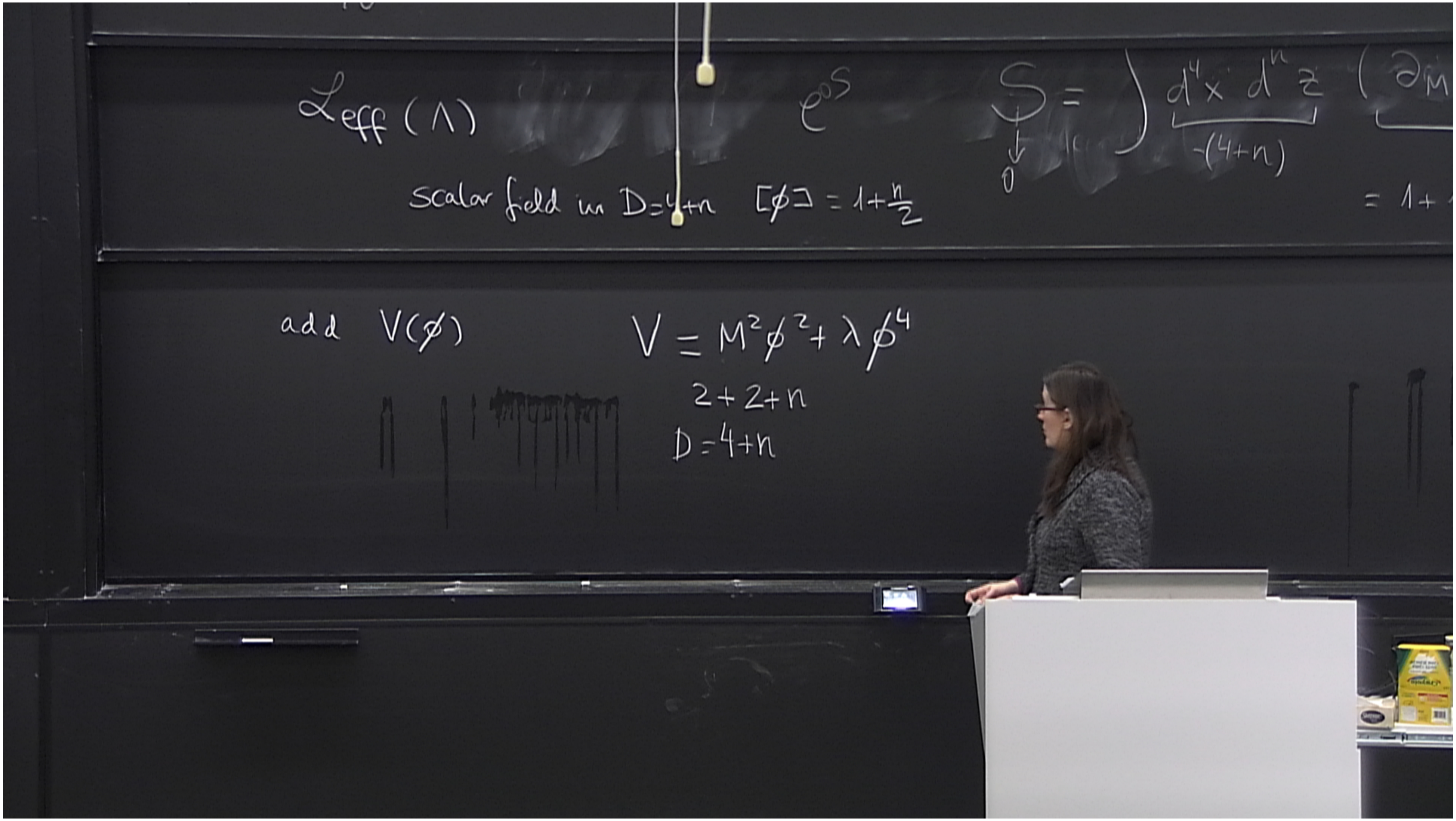

↳ test Newtonian dynamics, GR, SR ... 4D → XDIMS hidden → COMPACT
vacua ~ 10^{500}
Problem #1 Non-renormalizable
Theories in D > 4
D = 4+n
$\mathcal{L}_{eff}(\Lambda)$
$S = \int d^4x\, d^nz$

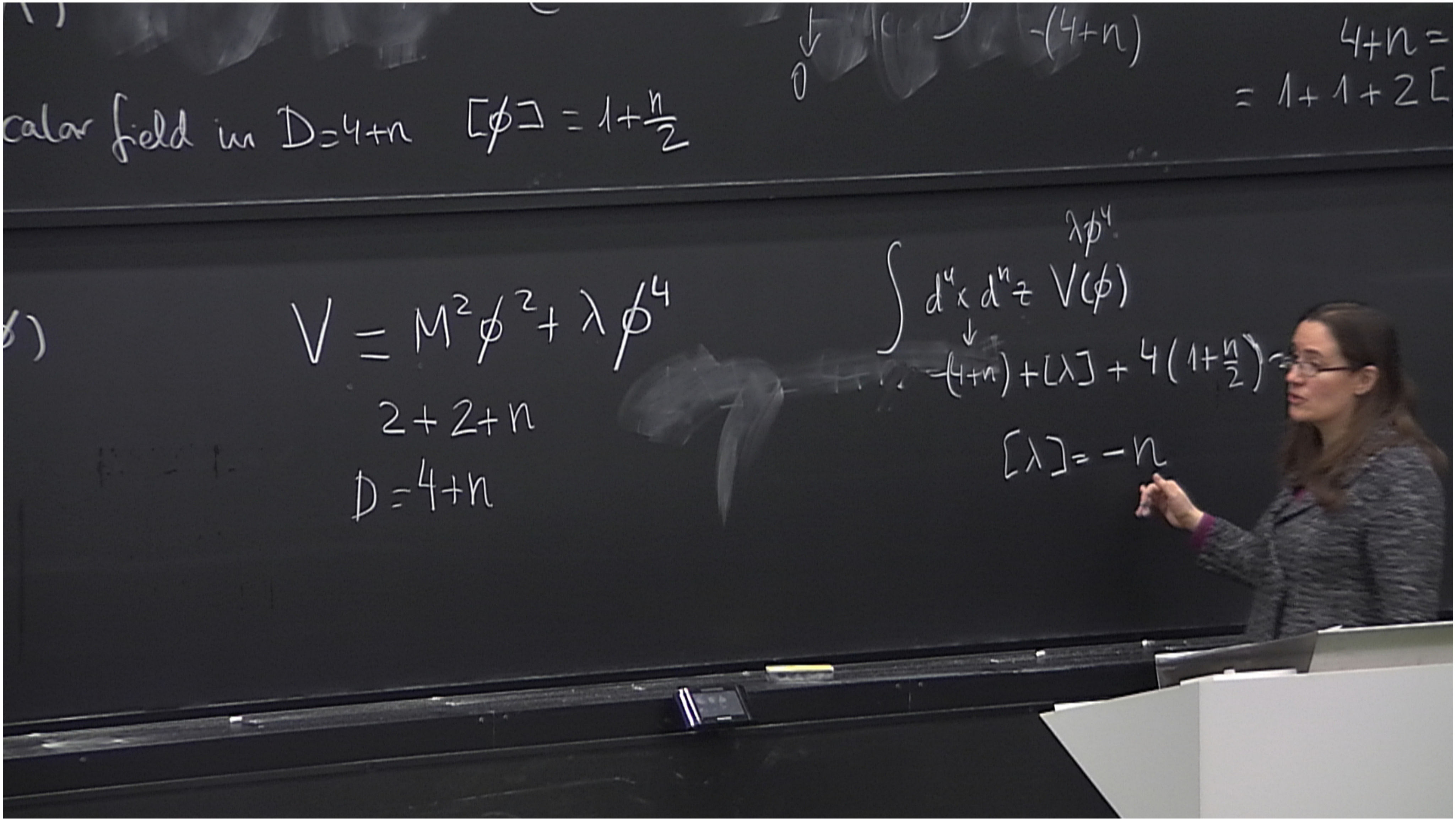

malizable
Theories in D > 4   D = 4 + n
extra dims
S = ∫ d^4x d^n z (∂_M φ ∂^M φ)


Theories in D > 4
D = 4 + n
extra dims
malizable
S = ∫ d^4x d^n z (∂_M φ ∂^M φ)

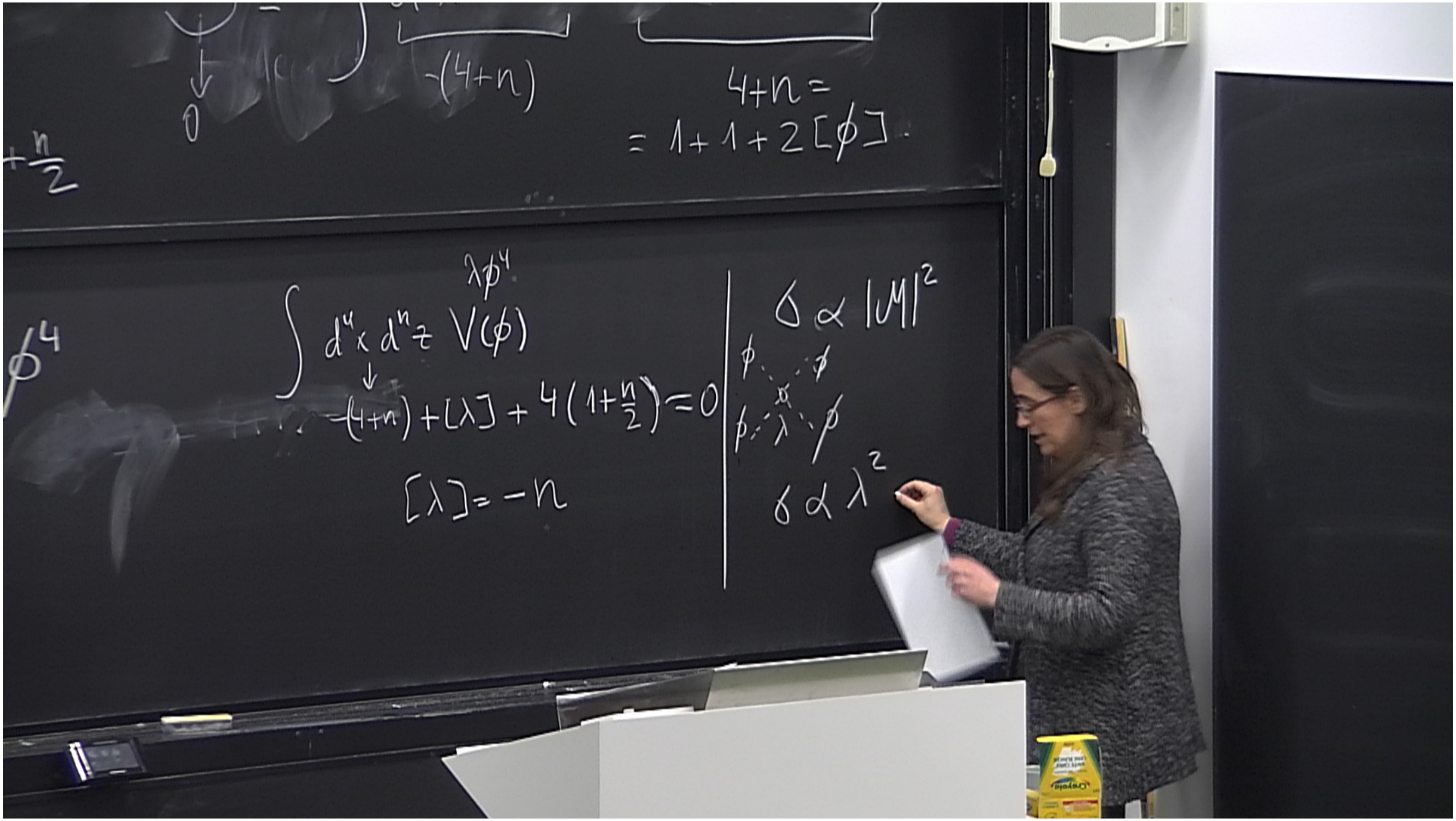

Problem #1 Non-renormalizable
Theories
$\mathcal{L}_{eff}(\Lambda)$
$e^{\delta S}$
$S =$
scalar field in D=4+n [ϕ] = 1


$\mathcal{L}_{eff}(\Lambda)$
e^{S}
$S = \int d^4x\, d^n z \,(\partial_M$
$-(4+n)$
0
scalar field in $D=4+n$ $[\phi] = 1+\frac{n}{2}$
$= 1+$
add $V(\phi)$
$V = M^2\phi^2 + \lambda\phi^4$
$4+n$


$\mathcal{L}_{eff}(\Lambda)$
e^{iS}
$S = \int \underbrace{d^4x\, d^nz}_{-(4+n)} \,(\partial_M$
$\downarrow$
0
scalar field in $D=4+n$ $[\phi] = 1+\frac{n}{2}$
$= 1+$
add $V(\phi)$
$V = M^2\phi^2 + \lambda\phi^4$
$2+2+n$
$D=4+n$



-(4+n)
4+n =
= 1+1+2 [
calar field in D=4+n [φ] = 1+n/2
λφ⁴
∫ d⁴x dⁿz V(φ)
V = M²φ² + λφ⁴
-(4+n) + [λ] + 4(1+n/2)
2+2+n
[λ] = -n
D = 4+n



-(4+n)
4+n =
= 1+1+2[φ]
λφ⁴
∫ d⁴x dⁿz V(φ)
-(4+n) + [λ] + 4(1+n/2) = 0
[λ] = -n
σ ∝ |M|²
σ ∝ λ²

scalar field in $D=4+n$ $\quad [\phi] = 1+\frac{n}{2}$

add $V(\phi)$

μ, e, ν, ν, G_F

$$V = M^2\phi^2 + \lambda\phi^4$$

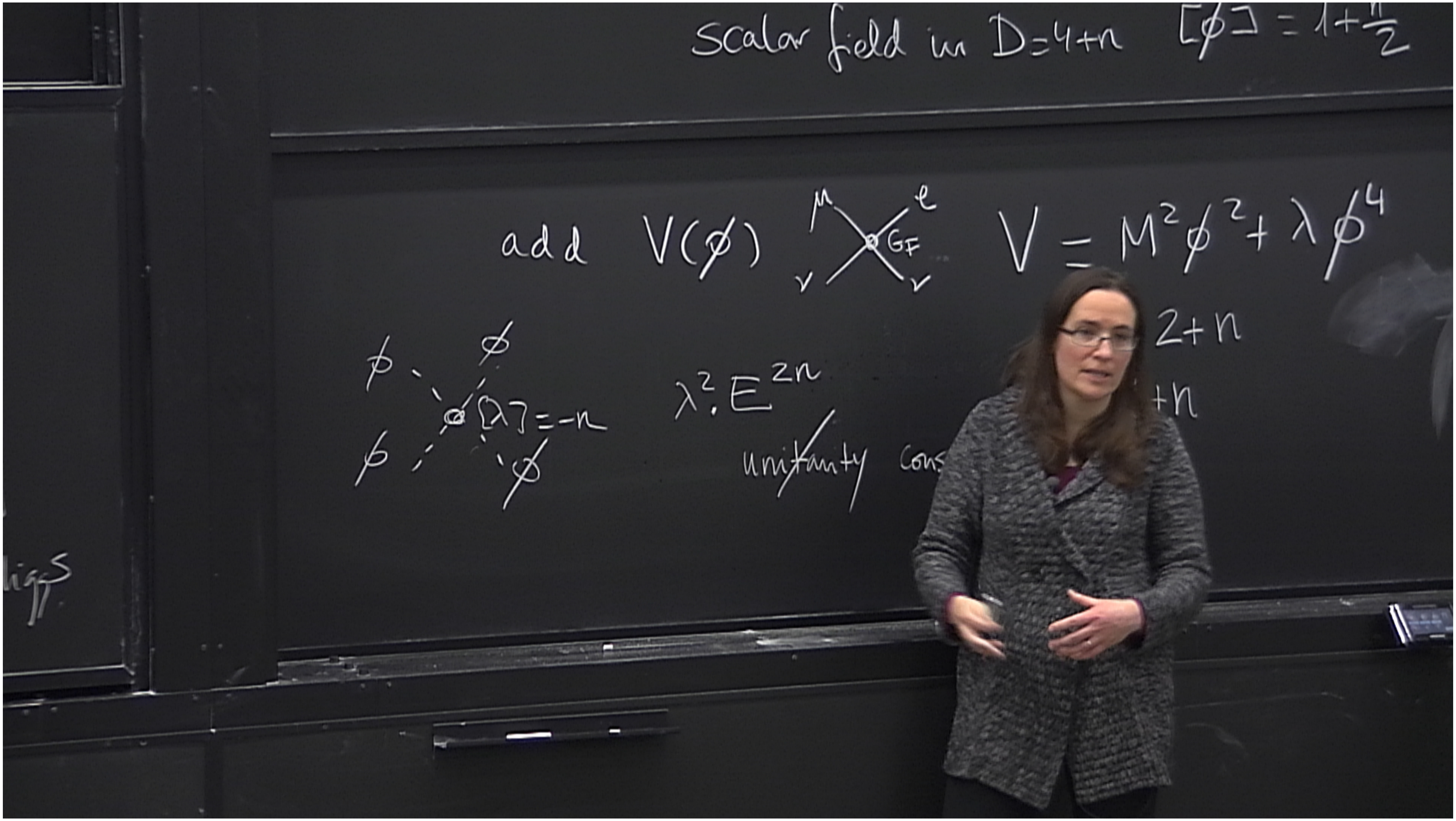
$2+2+n$

$D=4+n$

ϕ ϕ ϕ ϕ $\quad [\lambda] = -n$

$\lambda^2 \cdot E^{2n}$

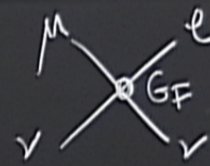
unitarity cons. probability


scalar field in D=4+n [φ] = 1+n/2
add V(φ)
μ e
G_F
ν ν
V = M²φ² + λφ⁴
2+n
+n
φ φ
φ φ
[λ] = -n
λ²·E^2n
unitarity cons
higgs

higgs

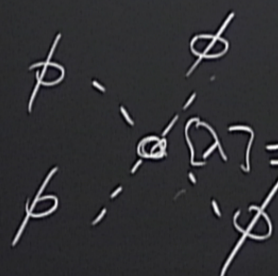
scalar field in $D=4+n$ $\quad [\phi] = 1+\frac{n}{2}$

add $V(\phi)$



$V = M^2\phi^2 + \lambda\phi^4$

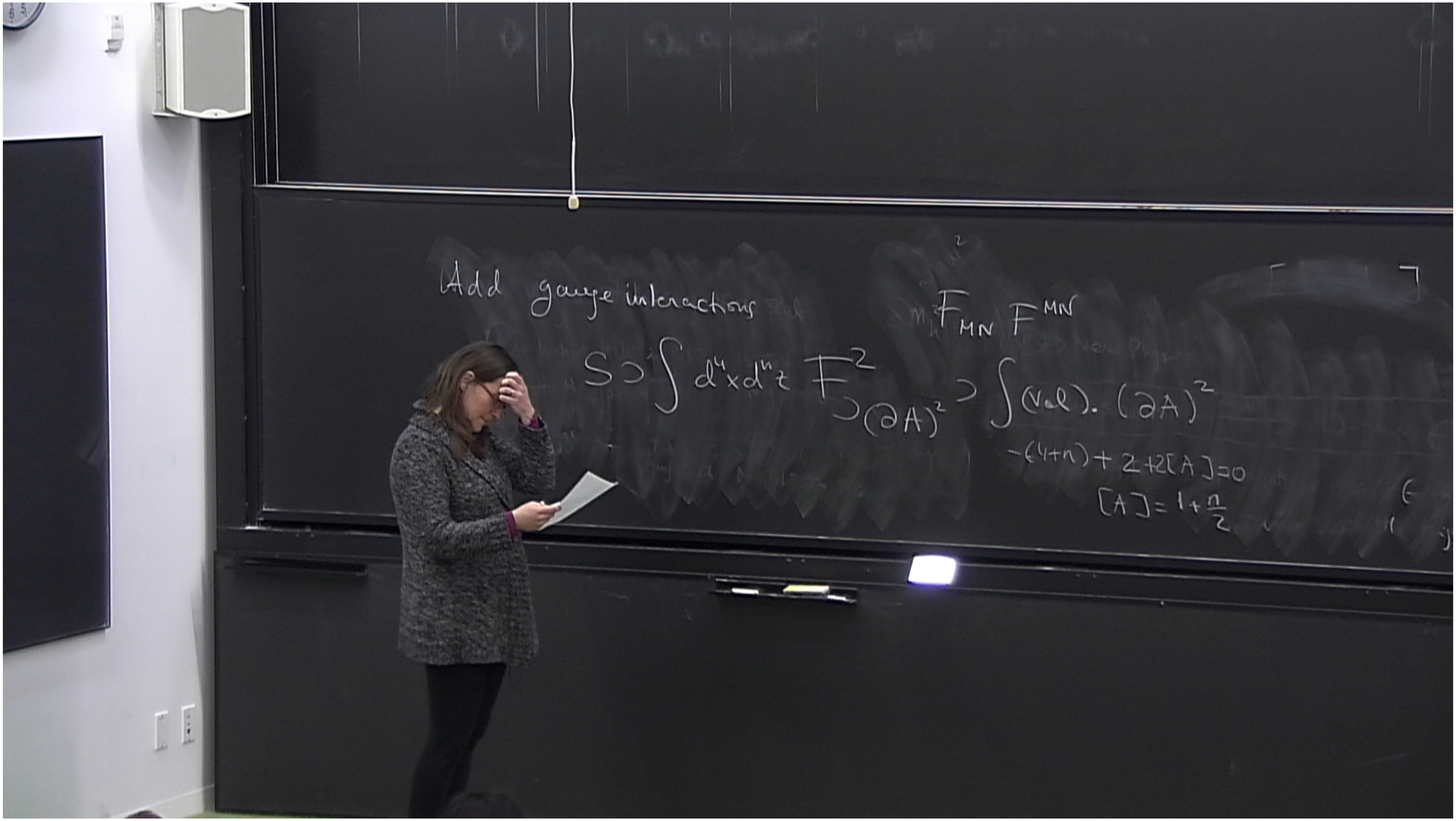
$2+2+n$

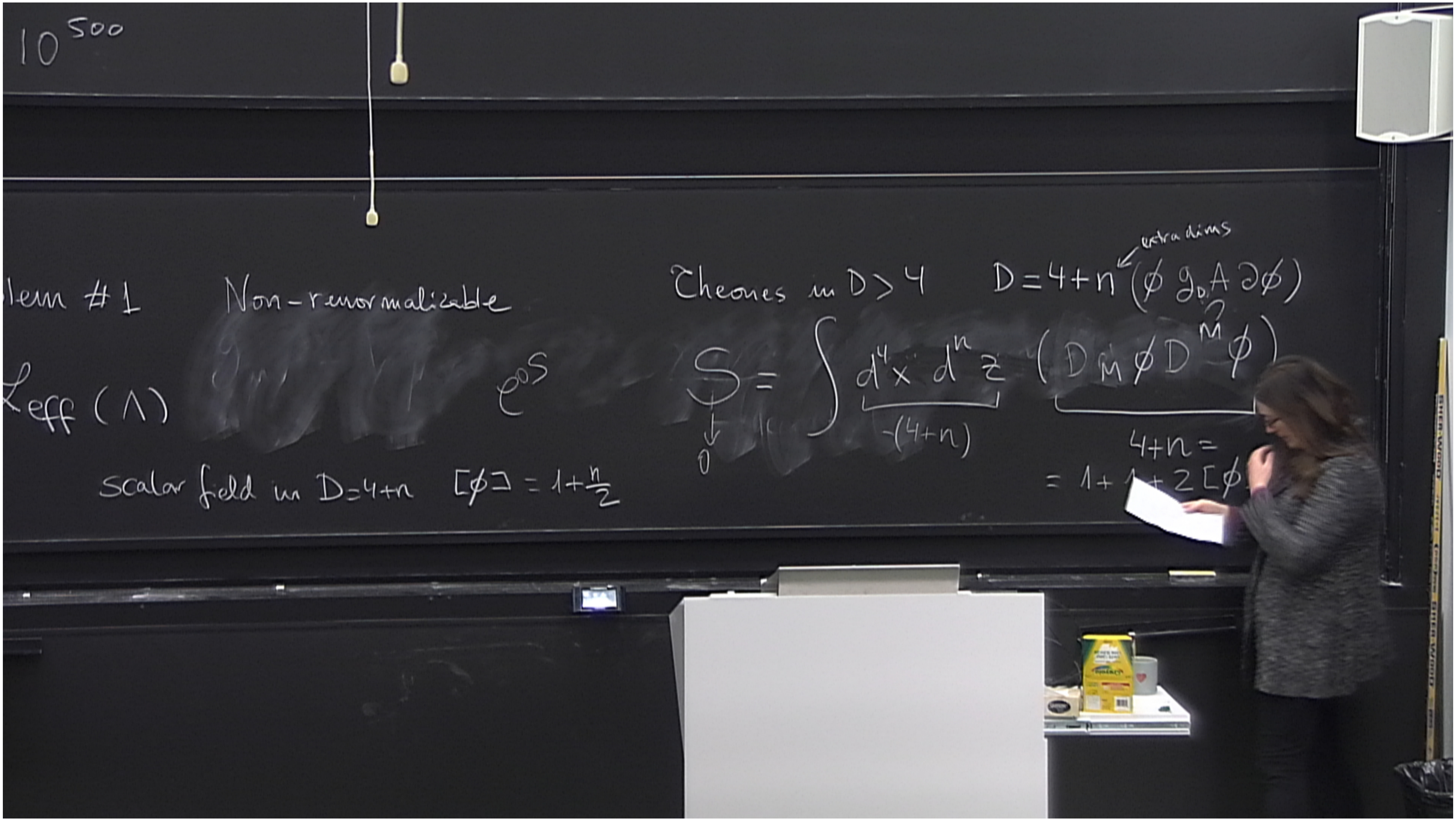


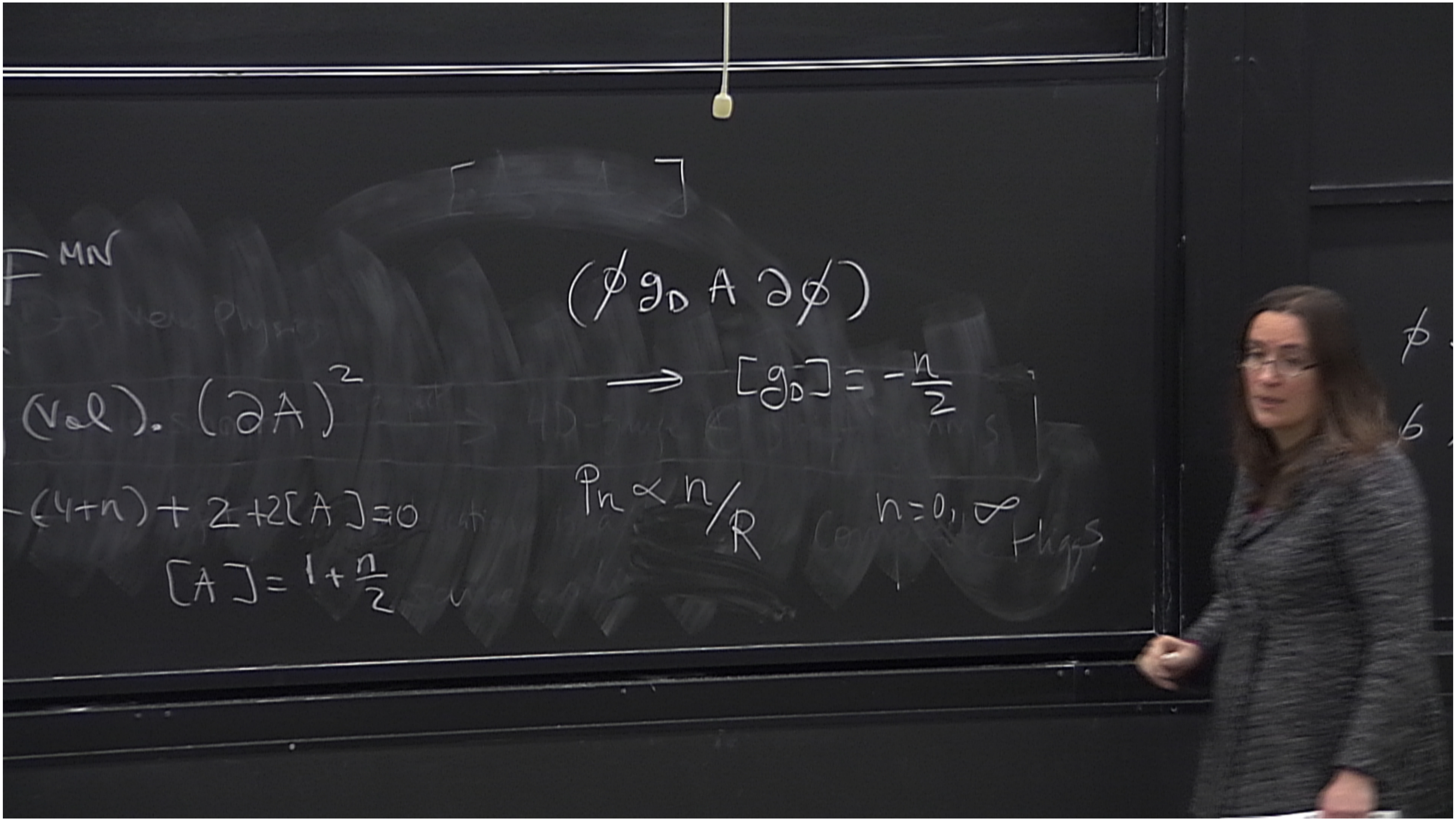
$[\lambda] = -n$ $\quad P \sim \lambda^2 E^{2n}$

$D = 4+n$

~~unitarity~~ cons. probability


Add gauge interactions
$F_{MN} F^{MN}$
$S \supset \int d^4x\, d^nz\, F^2 \supset (\partial A)^2 \supset \int (\mathrm{Vol}).\, (\partial A)^2$
$-(4+n) + 2 + 2[A] = 0$
$[A] = 1 + \frac{n}{2}$


10^500
lem #1 Non-renormalizable
Leff (Λ)
e^S
scalar field in D=4+n [φ] = 1+n/2
Theories in D>4 D=4+n (φ g_D A ∂φ)
extra dims
S = ∫ d^4x d^n z (D_M φ D^M φ)
-(4+n)
4+n =
= 1+


F^{MN}
$(Vol).(\partial A)^2$
$-(4+n)+2+2[A]=0$
$[A]=1+\frac{n}{2}$
$(\phi g_D A \partial\phi)$
$\longrightarrow [g_D]=-\frac{n}{2}$
$p_n \propto n/R$
$n=0,\infty$
Higgs

scalar field in $D=4+n$ $\quad [\phi] = 1+\frac{n}{2}$

add $V(\phi)$ $\quad G_F$ $\quad \nu \quad \nu$ $\quad V = M^2\phi^2 + \lambda\phi^4$

$2+2+n$

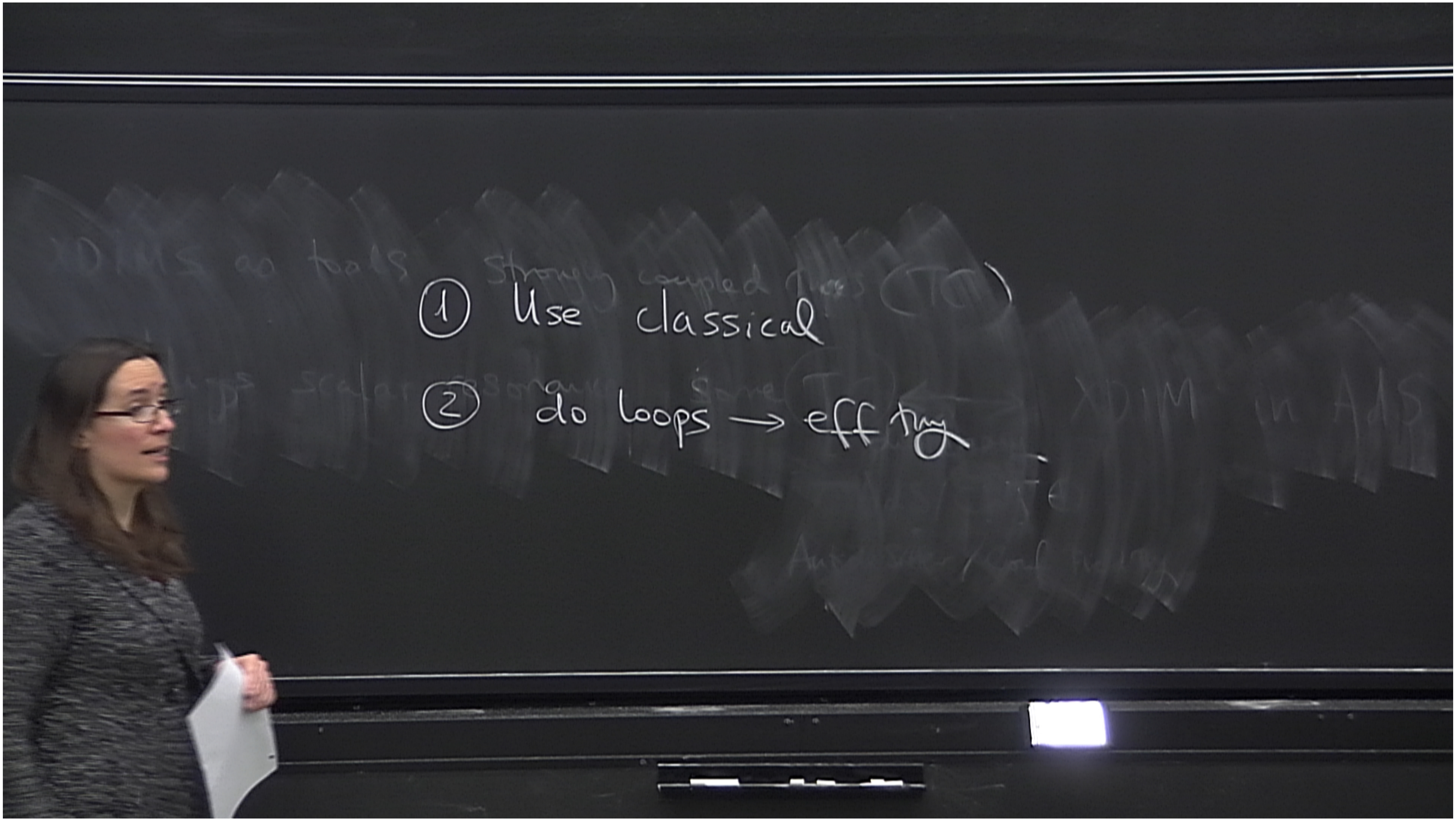
$\phi \quad \phi \quad \phi \quad \phi$ $\quad [\lambda] = -n \quad P \sim \lambda^2 E^{2n}$

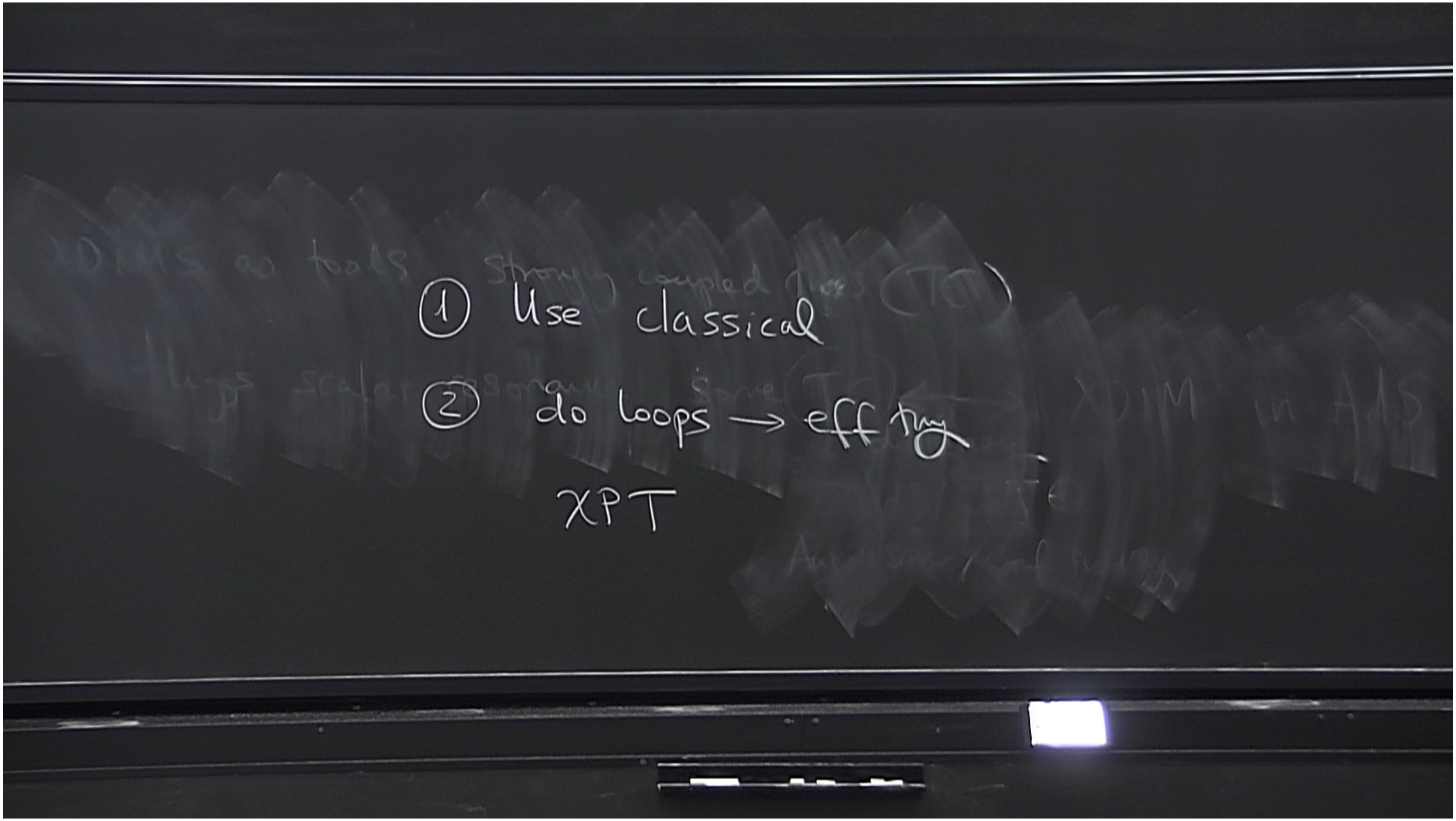
$D = 4+n$

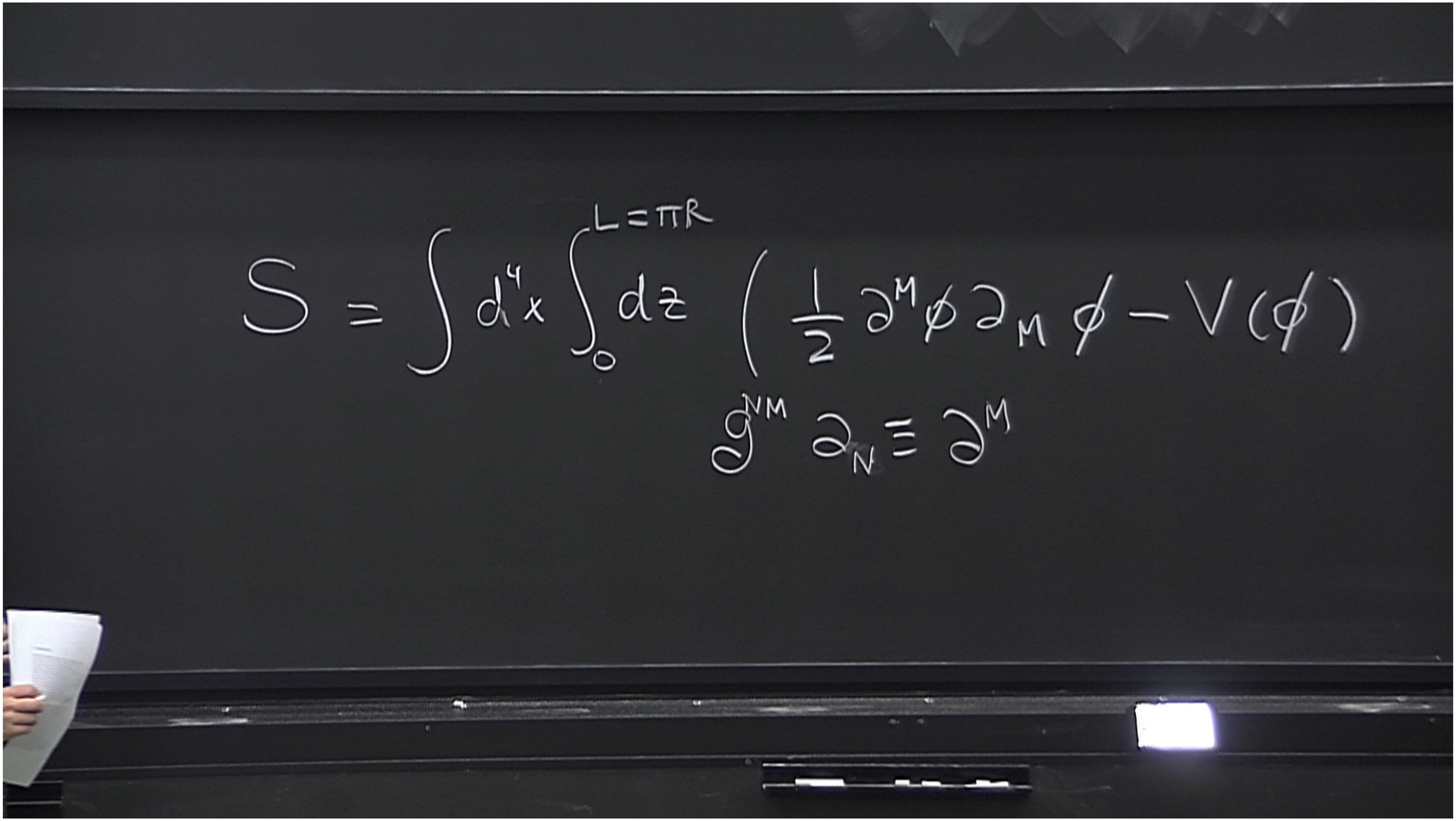
unitarity cons. probability

$D \rightarrow 4$

n compactified


① Use classical
② do loops → eff thy


① Use classical
② do loops → eff thy
XPT


$S = \int d^4x \int_0^{L=\pi R} dz \left(\frac{1}{2} \partial^M \phi \, \partial_M \phi - V(\phi) \right)$
$g^{NM} \partial_N \equiv \partial^M$

② do loops → eff thy

XPT

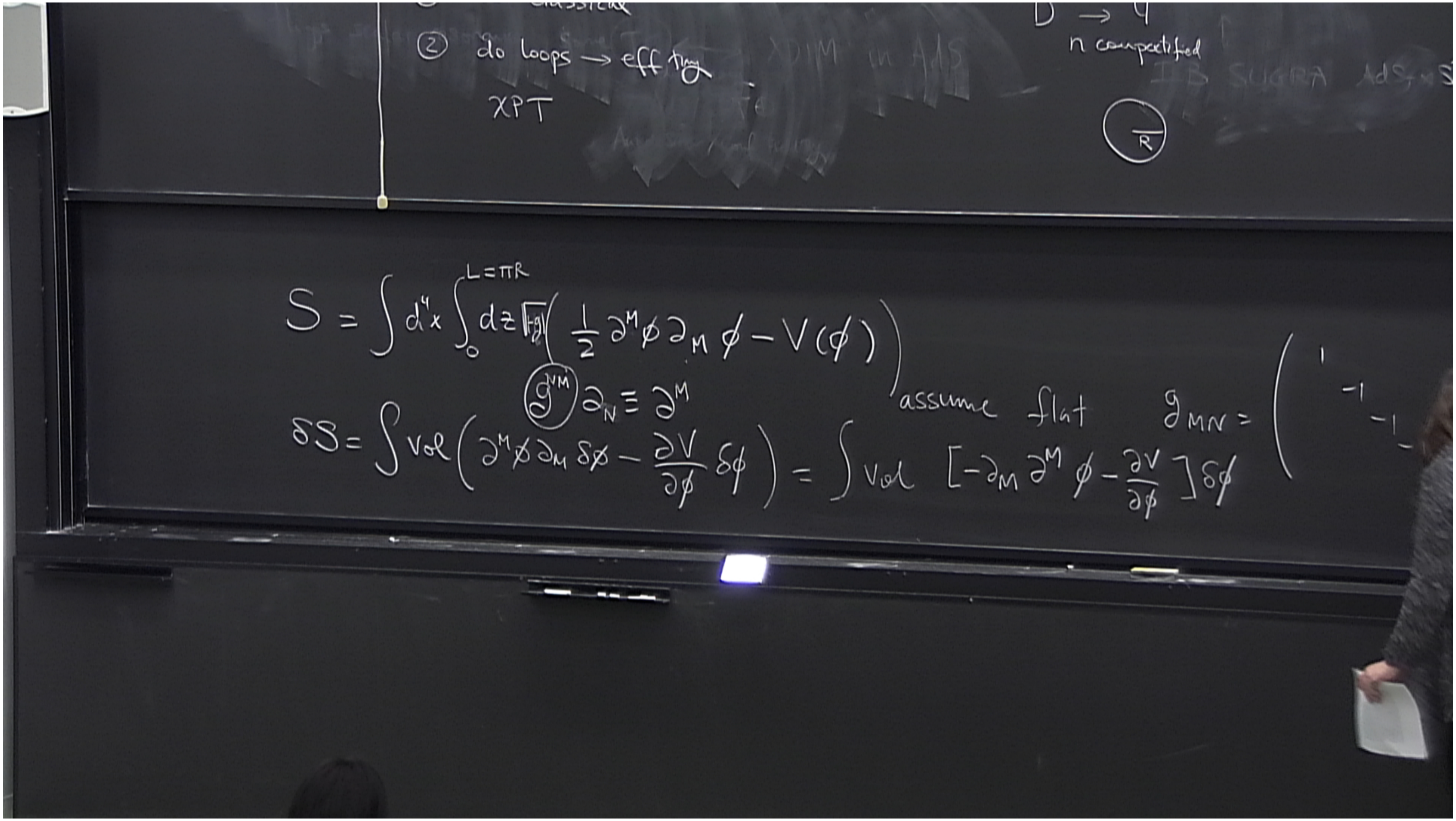
$D \to 4$

n compactified

$$S = \int d^4x \int_0^{L=\pi R} dz \sqrt{|g|} \left(\frac{1}{2} \partial^M \phi \, \partial_M \phi - V(\phi) \right)$$

$$g^{NM} \partial_N \equiv \partial^M$$

assume flat $g_{MN} = \begin{pmatrix} 1 & & & & \\ & -1 & & & \\ & & -1 & & \\ & & & -1 & \\ & & & & \ddots \end{pmatrix}$


classical
② do loops → eff thy
XPT
D → 4
n compactified
$S = \int d^4x \int_0^{L=\pi R} dz \sqrt{|g|} \left(\frac{1}{2} \partial^M \phi \partial_M \phi - V(\phi) \right)$
$g^{NM} \partial_N \equiv \partial^M$
assume flat $g_{MN} = \begin{pmatrix} 1 & & \\ & -1 & \\ & & -1 \end{pmatrix}$
$\delta S = \int \text{vol} \left(\partial^M \phi \partial_M \delta\phi - \frac{\partial V}{\partial \phi} \delta\phi \right) = \int \text{vol} \left[-\partial_M \partial^M \phi - \frac{\partial V}{\partial \phi} \right] \delta\phi$

② do loops $\to$ eff thy

XPT

$D \to 4$

n compactified

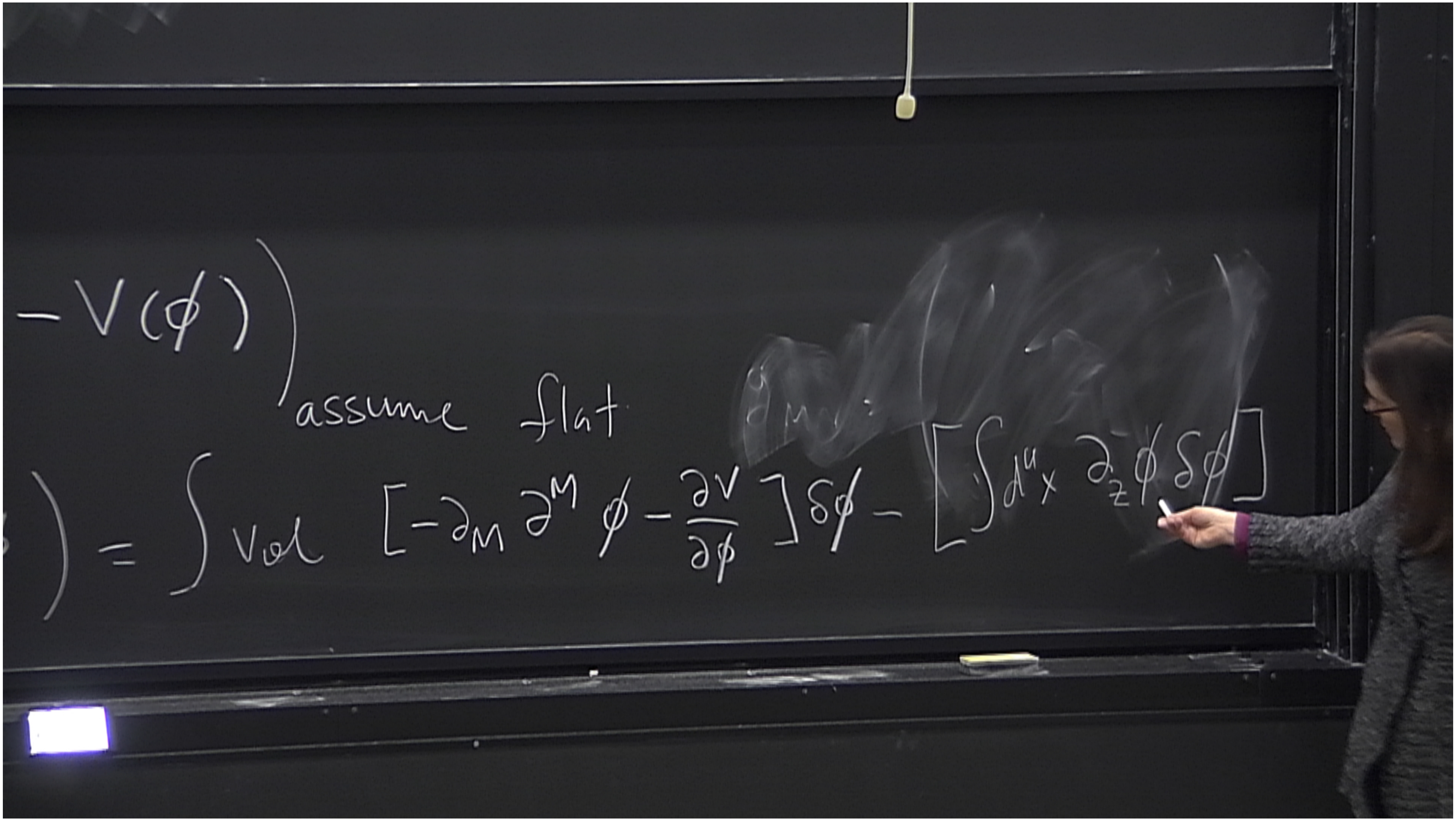
$\frac{}{R}$

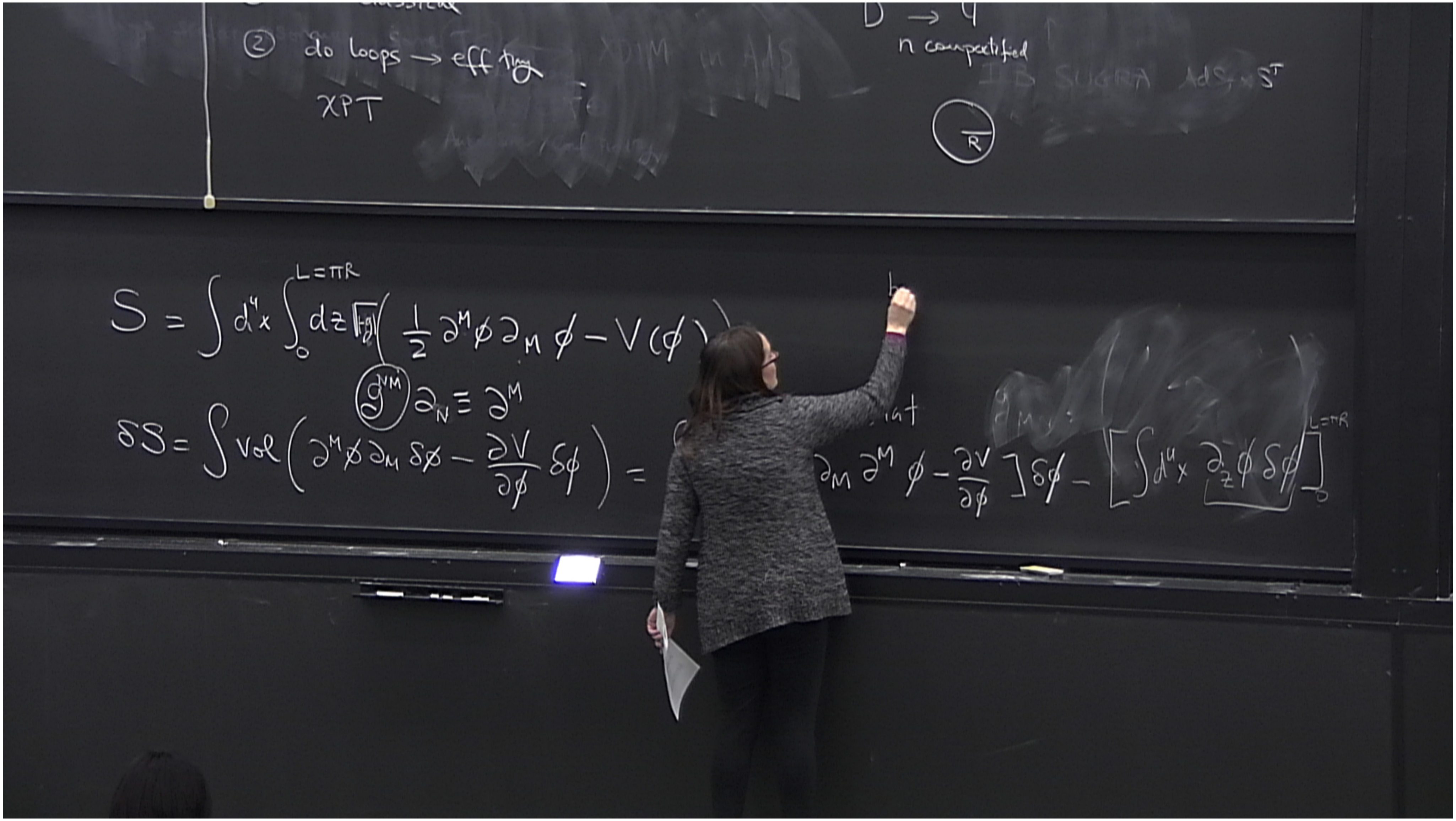
$$S = \int d^4x \int_0^{L=\pi R} dz \sqrt{|g|} \left(\frac{1}{2} \partial^M \phi \, \partial_M \phi - V(\phi) \right)$$

$$g^{NM} \partial_N \equiv \partial^M$$

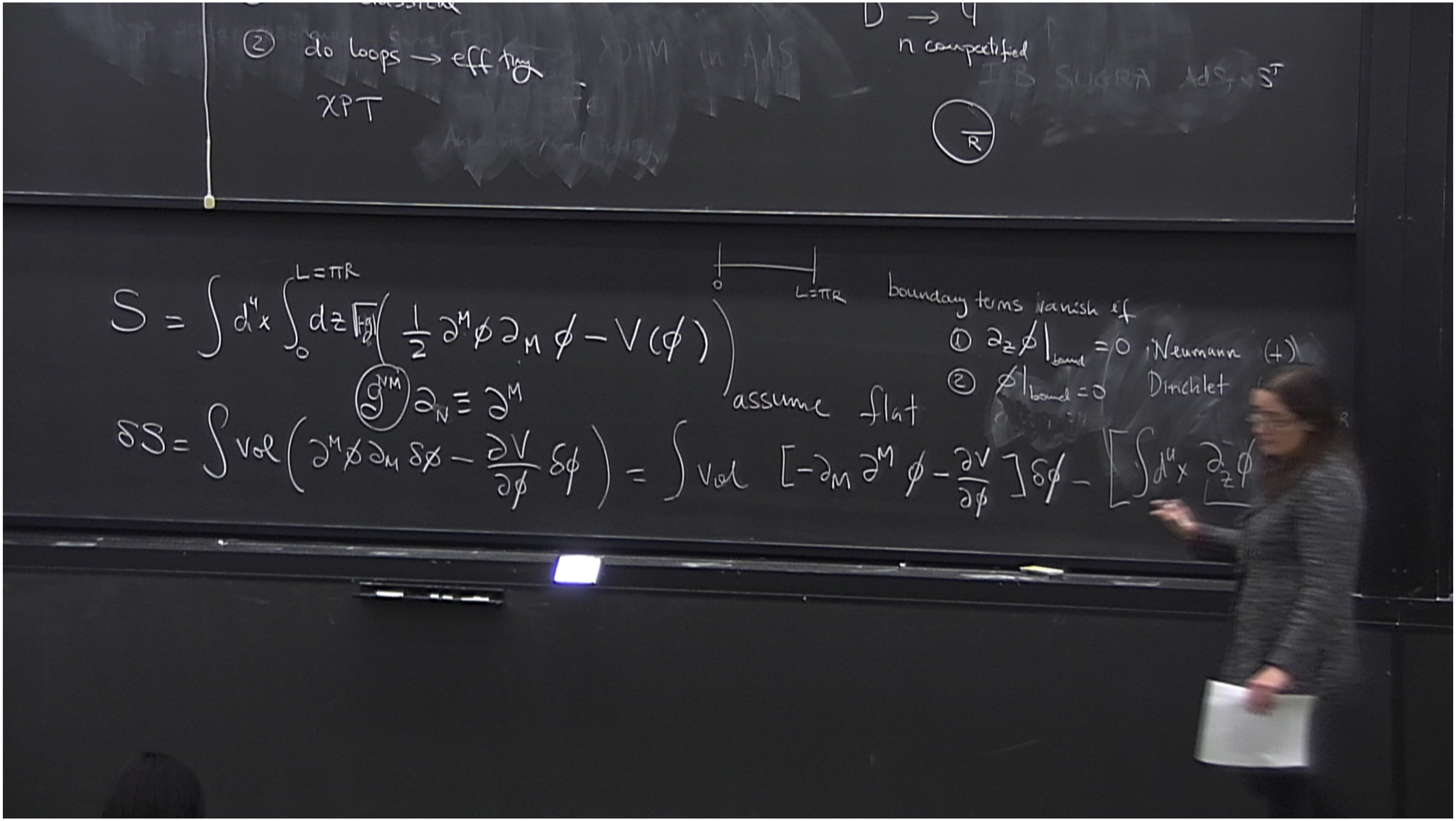
assume flat $g_{MN} = \begin{pmatrix} 1 & & & \\ & -1 & & \\ & & -1 & \\ & & & -1 \; \ddots \end{pmatrix}$

$$\delta S = \int \mathrm{vol} \left(\partial^M \phi \, \partial_M \delta\phi - \frac{\partial V}{\partial \phi} \delta\phi \right) = \int \mathrm{vol} \left[-\partial_M \partial^M \phi - \frac{\partial V}{\partial \phi} \right] \delta\phi$$


$-V(\phi)\Big)$
assume flat
$\Big) = \int vol \left[-\partial_M \partial^M \phi - \frac{\partial V}{\partial \phi}\right] \delta\phi - \left[\int d^4x \, \partial_z \phi \, \delta\phi\right]$



② do loops → eff thy
XPT
n compactified
IIB SUGRA AdS5 × S5
S = ∫d^4x ∫_0^{L=πR} dz √-g (1/2 ∂^M φ ∂_M φ − V(φ))
g^{NM} ∂_N ≡ ∂^M
δS = ∫vol (∂^M φ ∂_M δφ − ∂V/∂φ δφ) =
∂_M ∂^M φ − ∂V/∂φ] δφ − [∫d^4x ∂_z φ δφ]_0^{L=πR}


② do loops → eff thy
XPT
n compactified
IIB SUGRA AdS5 × S5
R
L = πR
0
L = πR
boundary terms vanish if
① ∂z φ|bound = 0 Neumann (+)
② φ|bound = 0 Dirichlet
assume flat
S = ∫ d4x ∫0L=πR dz √-g (1/2 ∂M φ ∂M φ − V(φ))
gNM ∂N ≡ ∂M
δS = ∫ vol (∂M φ ∂M δφ − ∂V/∂φ δφ) = ∫ vol [−∂M ∂M φ − ∂V/∂φ] δφ − [∫ d4x ∂z φ

② do loops → eff thy

χPT

$D \to 4$

n compactified

R

0 ——— $L = \pi R$

$$S = \int d^4x \int_0^{L=\pi R} dz \sqrt{-g} \left(\frac{1}{2} \partial^M \phi\, \partial_M \phi - V(\phi) \right)$$

assume flat

$$g^{NM} \partial_N \equiv \partial^M$$

boundary terms vanish if

① $\partial_z \phi \big|_{bound} = 0$ Neumann $(+)$

② $\phi \big|_{bound} = 0$ Dirichlet $(-)$

$$\delta S = \int vol \left(\partial^M \phi\, \partial_M \delta\phi - \frac{\partial V}{\partial \phi} \delta\phi \right) = \int vol \left[-\partial_M \partial^M \phi - \frac{\partial V}{\partial \phi} \right] \delta\phi - \left[\int d^4x\, \boxed{\partial_z \phi\, \delta\phi} \right]_0^{L=\pi R}$$